AT(11-1)-1199
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Illinois State Water Survey
at the
University of Illinois
Urbana, Illinois

STUDY OP RAINOUT OP RADIOACTIVITY IN ILLINOIS

Second Progress Report
Contract Number AT(11-1)-1199
January 31, 1964

Sponsored by

United States Atomic Energy Commission
Fallout Studies Branch
Division of Biology and Medicine
Washington 25, D. C.

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ACKNOWLEDGMENTS

The program was carried out under the general direction of G. E. Stout, Head, Meteorology Section. Douglas Jones supervised the radar observations and the mobile sampler operations, and assisted in the analyses of the radar and meteorological data. Rena Gans supervised the gross beta analyses and assisted in the analyses of other data.

Special credit is due G. R. Boyd for development of the automatic time sampler upon which success of the program is highly dependent. Mr. Boyd also supervised the installation, operation, and maintenance of the rainwater sampling network and assisted in some phases of the data analyses. Daniel Watson assisted in servicing of the sampling network and in the data analyses. Ronald" Tibbetts assisted in servicing of the sampling network and in maintenance and modification of the equipment. Dr. J. C. Neill and Robert Sinclair developed a computer program that facilitated analyses of the radar data.

Credit is due the cooperative observers who were responsible for the operation of the time samplers during storm periods. We are indebted to Dr. P. F. Gustafson, Argonne National Laboratory, for furnishing equipment for the GIGI flights and to personnel of Chanute Air Force Base who carried out the GIGI flights under our supervision.

INTRODUCTION

On June 1, 1962, the Illinois State Water Survey entered into a 12-month contract with the Atomic Energy Commission. Under this contract, research was conducted on the rainout of radioactivity, with particular emphasis upon its variability in space and time and its relationship to precipitation characteristics. During Spring 1963, the State Water Survey cooperated with the AEC, U. S. Weather Bureau, Pennsylvania State University, and other interested groups in a detailed field program aimed toward determining the conditions under which radioactive debris is transferred from the stratosphere to the troposphere and then to the surface. This program was carried out under the supervision of Professor Edwin Danielson of Penn State. A supplement of $16,000 to the existing contract was granted by AEC to enable Water Survey participation in this program.

The contract with AEC was extended for another 12 months on June 1, 1963 through negotiation of a supplemental agreement to Contract No. AT(11-1)-1199. Under this supplemental agreement, research is being performed: to determine the time distribution of radioactivity in storms on an areal basis; to establish relations between radioactive rainout and various rainfall factors; to ascertain characteristics of the radioactive rainout as revealed by radar observations and analyses; to evaluate the effects of cloud type and drop-size distribution of raindrops on rainout; and, to develop a technique for aircraft sampling of rainwater below cloud bases.

Since the last progress report (Huff, 1963), analyses have been concentrated on determination of the characteristics of the time and space distribution of radioactivity in convective storms, and the relationship of the radioactivity distribution to the rainfall rate profile through storms. Analyses of the 1962 strontium data have been completed. The 1962 study of the spatial variability of radioactive rainout on two small networks of 10 and 12 square miles has been extended to evaluate the magnitude of the spatial variability on a 400 square mile area. Further evaluation has been made of the relationship of the concentration and deposition of radioactivity in storms to storm rainfall volume, duration, and intensity, in continuance of the 1962 study.

Preliminary analysis of a small amount of 1963 strontium data has been completed. A considerable amount of radar data has been collected in conjunction with 1963 storms, and correlation of these data with the radioactive rainout is underway. This progress report is devoted to discussion of the analyses listed above, description of the 1963 data collection program, and equipment development and modification. Analysis results are based primarily upon gross beta data, since only 85 of the 400 rainwater samples forwarded to Isotopes, Inc., during 1963 for isotope analyses had been returned when this report was started. Analyses of these data will be presented in a future research report.

DATA COLLECTION PROGRAM

Rainwater Sampling Networks

During 1963, rainwater samples were collected on the networks shown in Figure 1. The outer border in Figure 1 encompasses the network operated during April and May in conjunction with Project Springfield under Professor Danielson's direction. The network consisted of 16 automatic time samplers within an area of approximately 6000 square miles in central Illinois. These time samplers, described in the last progress report, were capable of obtaining 1 to 12 samples in a storm without human attention. Also at each of these sampler stations were a recording raingage to provide data

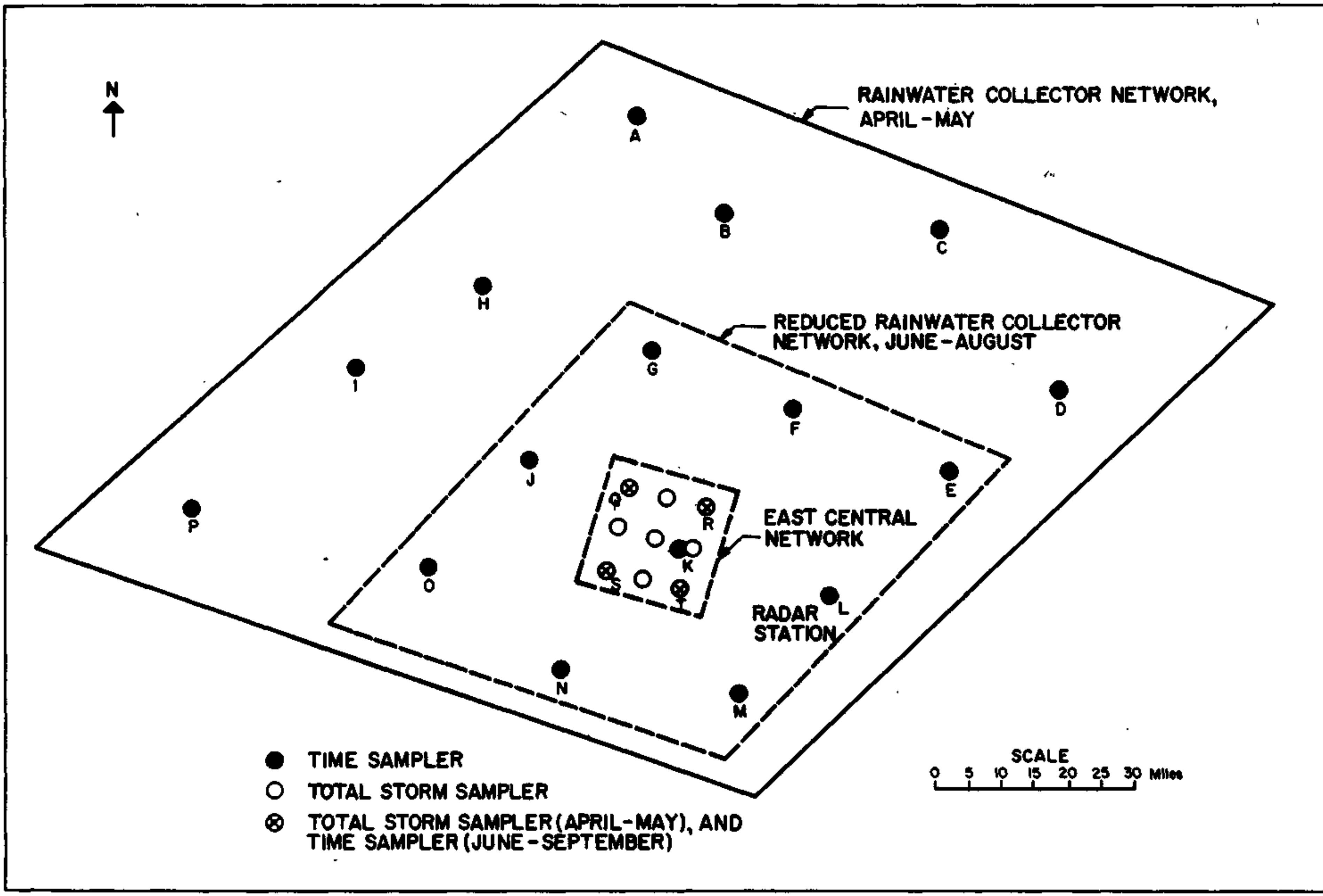


FIG. 1 1963 RAINWATER COLLECTOR NETWORKS IN CENTRAL ILLINOIS on the volume, duration, and intensity of rainfall, and a total storm sampler (baby bathtub) described in the previous progress report.

During June and July, the outer ring of time samplers was removed, and the network reduced to approximately 3000 square miles as indicated in Figure 1. This was done to facilitate servicing and to increase the time sampler density on the East Central Illinois network of 400 square miles (inner area, Fig. 1). The outer ring of time samplers was used to activate stations Q, R, S, and T in Figure 1. Station K on the East Central Illinois network remained from the Project Springfield network. During August, only the five time samplers on the East Central Illinois network were operated. In addition, nine total storm samplers were operated throughout the spring and summer on the 400 square mile network, as shown by the open circles in Figure 1.

Each of the time samplers was located at the residence of a cooperative observer who was paid to service the sampler. The observers were alerted by the project meteorologist several hours prior to anticipated rainfall so that the samplers could be washed and checked for operation. At the end of each storm, the cooperative observer removed the sample bottles, labeled them, and stored them for collection. Water Survey technicians visited the time sampler network once each week to service the recording raingages, check on the time sampler operations, and collect the rainwater samples.

In addition to the sampling networks described above, five total storm samplers were operated within an area of 100 square miles in the center of the Water Survey's Little Egypt raingage network in southern Illinois (Fig. 2). This raingage network encompasses 550 square miles and is located approximately 150 miles south of the Central Illinois network in Figure 1.

Radar Observations

Radar storm observations were made primarily with the TPS-10 and the CPS-9. The CPS-9 has the capability for both horizontal and vertical scanning of storms, and the TPS-10 is a range-height-indicator for observing the vertical distribution of clouds. The tracking portion of an M-33, 3-cm radar was used occasionally to obtain vertical profiles in storms moving over the radar station. Most of the data on the vertical structure of storms was obtained with the TPS-10 during 1963. The CPS-9 was used largely for determining the areal extent, movement, and relative intensity of the storm echoes.

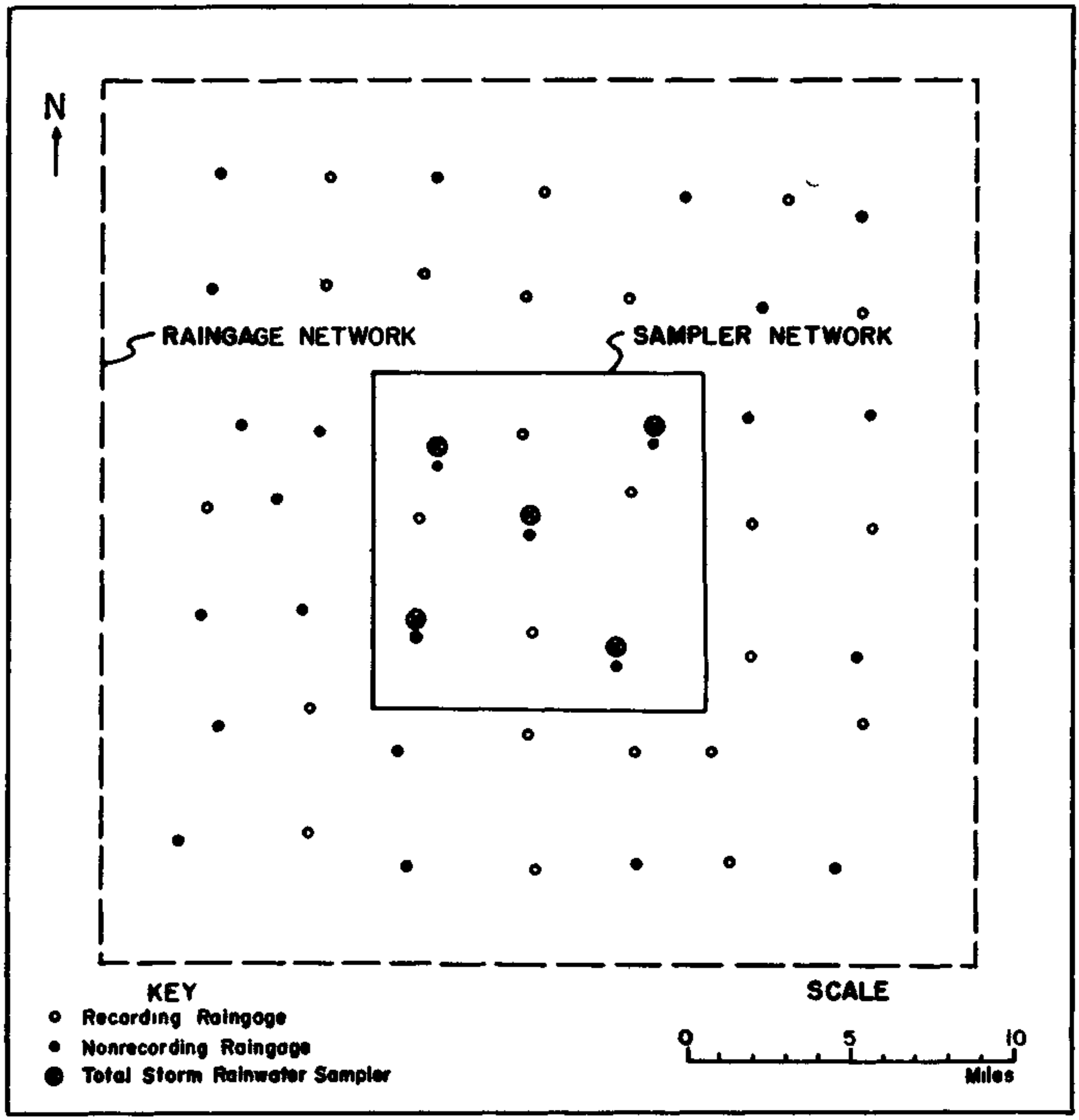


FIG. 2 LITTLE EGYPT NETWORK

Time Sampler Development and Modification

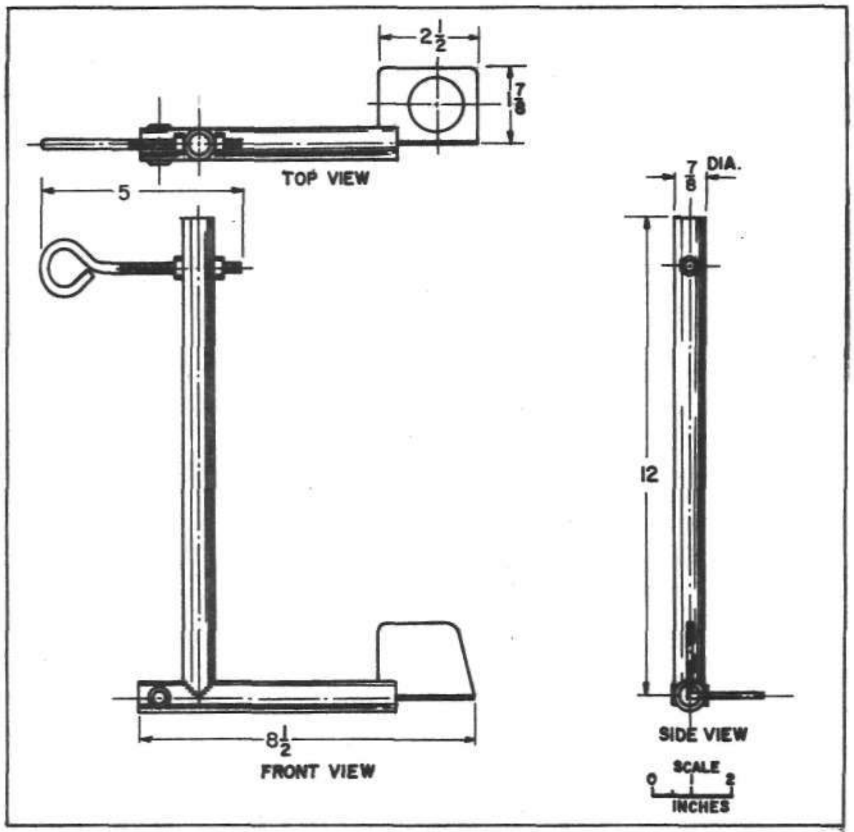
The automatic time sampler, described in the last progress report, was briefly field tested during early spring 1963. With the activation of Project Springfield in April, 16 of these time samplers were quickly constructed and installed in the field by April 15. Although it was necessary to construct and install the time samplers without completion of the field testing, the operation was quite successful for an initial model, and a relatively large amount of data was collected during the spring and summer. The samplers were capable of collecting 1 to 12 samples in a storm without human attention. Each sample bottle normally contained 0.04 to 0.06 inch of rainfall, although this amount varied somewhat depending upon wind conditions.

However, two modifications of the initial model have been made since the closing of field operations in early September. A new method of holding the bottles on the sampler has been designed, constructed, and field tested. Tests have been successful and the modification is being made to all 16 time samplers in preparation for opening of the rainwater network in March 1964.

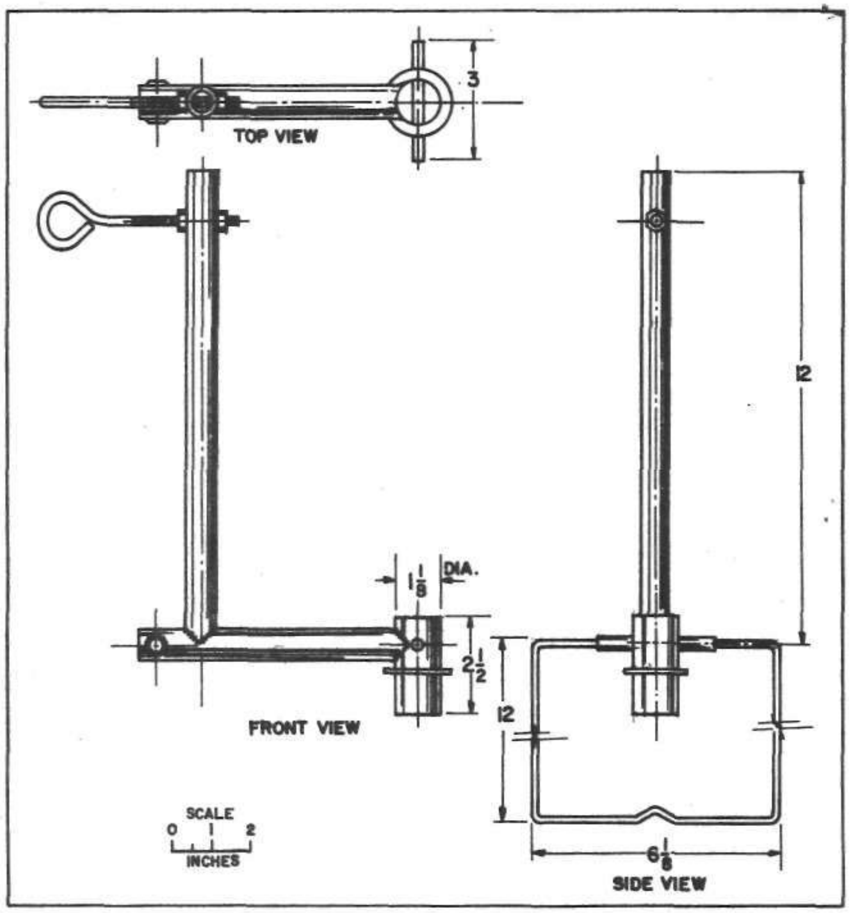
The modification of the bottle support method is illustrated in Figure 3. On the original model, the neck of the sampling bottle extended through the support flange and was held in place by the bottle cap which was drilled to allow water to pass into the sampling bottle. The major disadvantages of this method were: (1) the neck of the sampling bottle was sufficiently flexible that, when a sudden force was applied during rotation, the bottles frequently dropped off, and (2) the bottles could move in the support flange because of the minimum thickness of the flange, and the resulting misalignment could cause a portion of the sample to be lost.

On the modified model, the bottle neck is slid onto a guide tube and is held rigid by a steel yoke down the sides and under the bottle. This eliminates dropping of the bottles from rotational forces. There are also no problems due to misalignment because the rainwater sample passes through the guide tube and deep into the sample bottle neck.

A timing mechanism has been designed and tested and will be incorporated into the time sampler assembly before 1964 field operations are begun. During 1963, the starting and ending time of each time sample had to be determined from the recording raingage at the sampler station. When a complete set of samples was not obtained because of jamming of the sampler rotator, or when the 12 sample bottles were filled before a storm period ended, it was difficult to evaluate the starting and ending time for each time sample.



a. Original Model



b. Modified Model

FIG. 3 BOTTLE SUPPORT METHOD.

The timer operates as follows. A pen arm which is set to run on the zero line of the recording chart, and a 6 v.d.c. relay coil are attached to a recording raingage. A micro switch, set to trip as each bottle passes on after being filled, is mounted on each time sampler. As this switch is tripped it closes the circuit to the relay coil which activates the pen arm to produce an event mark on the recording raingage chart.

Mobile Rainwater Collectors

Pour precipitation collectors were constructed of black sheet iron in the form of rectangles 48 inches wide, 60 inches long, and 6 inches deep. These tanks were coated with black polyethylene plastic on the interior and black rust-inhibiting paint on the outside. The tanks were placed in commercial car top carrier racks and adjusted with suitable wooden supports to cause the collected precipitation to drain to the corner above the driver. The normal operating procedure was for the driver to be directed to the desired collection point by radio communication with the radar operator. The driver would collect the precipitation in polyethylene bottles by means of flexible tubing from the tank, and determine the collection duration for each bottle with a stop watch.

The purpose of the car top collectors was to enable the collection of precipitation at desirable points other than where the permanent automatic collectors were located. It was further desired to have two car top collectors under the same storm, spaced so that one car would collect water at the center of the storm while the other was collecting water near the edge. This purpose is best served in the case of air mass type thundershowers.

The collection of rainwater was tried on one day in 1963. Two cars were used, but poor results were obtained because of inexperience of the observers and dissipation of the storm as it moved into the area of interest. Air mass thundershowers occurred on only one other day (July 1) in east-central Illinois during the time the car samplers were in operation, and these showers were at the operating limit of the mobile communications so that collection was not attempted.

The collection of rainwater through the use of mobile collectors is still a desirable procedure. The purchase of newer type radio equipment promises to improve communication with the mobile collectors. Essentially the same type of data collection is desirable; however, because of the low frequency of air mass thundershowers, the probability of more than two or three cases per season is not great.

In addition, the mobile collectors may be used as supplementary collectors between the permanently fixed collectors on the time sampler network. This would be desirable in those situations where an all-out effort toward collection of precipitation is made.

Aircraft Sampler

One of the studies underway is the development of a technique for the airborne collection of rainwater below cloud bases. There has been considerable question as to the amount of radioactive debris that is scrubbed from the atmosphere between the cloud base and the ground. If samples of water could be collected at cloud bases along with simultaneous collections at the ground level, it might be possible to ascertain the scrubbing influences.

An air-water scoop that can be placed in the window next to the co-pilot of a Twin Beech aircraft is used for the water collection. The scoop is a half of a hemisphere with an opening of 115 square centimeters. The scoop decreases in size so that the intake into the aircraft is 46 square centimeters. Assuming collection efficiency of 100 percent at an aircraft speed of 50 m/s water would be collected as follows:

Rain Rate (mm/hr)	Water Collected (cc/min.)	Time (min.) to collect 0.l Liter
10	16	6
25	39	2.5
100	146	0.7

The water and air flow into the aircraft through a 3-inch plastic tube into a centrifuge where the air and water are separated. The housing for the centrifuge is a large polyethylene tank in which the air and water circulate around the center cylinder. Air is exhausted through this center cylinder. Some back pressure has been experienced in the collector and centrifuge which must be eliminated before more water samples are collected.

Considerable difficulty has been experienced in scheduling flights on days of stable precipitation. Plights are not attempted on days with thunderstorm activity because of the flight hazards. Flights were made on three days with light rainfall in 1963. Unfortunately, the rainfall decreased in intensity or was too light to obtain samples of sufficient quantity for analysis. Drought conditions during late summer and fall handicapped the data collection. Efforts will be made to continue the program in 1964.

Surface Air Sampler

A ground-based air sampler, ANL No, 125972, was provided by the Argonne National Laboratory for the collection of surface air samples. Between April 23 and August 6, 17 filters were exposed. Appreciable differences in the concentration of radioactivity in the air was observed on several storm days. For example, on June 10 an increase in concentration of 60 percent occurred after the passage of two squall lines at the sampling site. Further analyses will be performed to evaluate this data in conjunction with storm case studies.

GIGI Flights

In conjunction with Project Springfield, observations were made of gamma radiation profiles in the atmosphere. Arrangements were made with personnel at Chanute Field Weather School to release balloons with a GIGI attached. The GIGI instruments were provided by Argonne National Laboratories. The Water Survey provided one or two people to direct the flight and to assist in the balloon release. Data were received by the Survey and forwarded to Argonne National Laboratories for processing.

In order to recover the GIGI instruments, the Illinois and Indiana State Police, the Air Force tracking radar unit at Rockville, Indiana and the University of Illinois Security Department were enlisted to either track or recover the instruments. On occasion news releases were telephoned to radio or television stations near the descent point of the balloon to advise the public to look for the instrument. In most cases the instrument was recovered within 24 hours. All nine instruments were found and returned to Argonne National Laboratory for refurbishing.

Balloon launchings were made on two days in April, five days in May, and two days in June. Appreciable variations in the vertical profile of gamma radiation were observed on most of the flights, but the significance of the observed changes has not been determined at this time. Further analyses of the gamma data are planned, and the data will be made available to other investigators associated with Project Springfield.

Sampling Program

Under the AEC contract, provision was made for radiochemical analyses of 400 rainwater samples for strontium-89 and strontium-90. These analyses are being made by Isotopes, Inc., of Westwood, New Jersey, as a subcontractor. Gross beta analyses have been made at facilities of the State Water Survey.

At the time that preparation of this report was undertaken, radiochemical analyses had been completed on only 85 of the 400 rainwater samples submitted to Isotopes, Inc. These 85 samples were collected during April in conjunction with Project Springfield. Dr. Friend of Isotopes, Inc., has undertaken some radiochemical analyses in addition to the subcontract requirements. In some storms, through mutual agreement, he is providing radiochemical analyses of Ce-144, Zr-95, and Mn-54, either as a substitute or an addition to the standard strontium analyses.

Table 1 shows a tabulation by storm date of the number of time samples and total storm samples for which gross beta and strontium analyses have been or are being made in 1963. The number of stations involved in the time sample collections is shown also. Thus, 815 time samples from 115 stations and 214 total storm samples, or an over-all total of 1029 samples, were analysed for gross beta in 1963. Additional total storm analyses were obtained when time samples spanned a complete storm so that the average of the individual samples provided a total storm measurement. The samples listed in Table 1 were selected for the analyses from approximately 2800 samples obtained from the time samplers and total storm samplers during 1963 field operations.

DATA PROCESSING STATUS

A number of factors entered into the selection of storm rainwater samples for radiochemical analyses. A major factor was the completeness of the observational data during a given storm, which was dependent upon operations of the radars, raingages, and automatic time samplers. As indicated earlier, a portion of the data was unsuitable for certain detailed analyses because of incomplete sampling throughout a storm period caused by equipment problems or storms too heavy to be completely sampled with the 12-bottle time sampler. Efforts were made to include (1) storms of varying rain type and synoptic type, and (2) storms distributed throughout the spring and summer seasons. Selections were made to include rainstorms of varying duration, intensity, and volume, and storms with various degrees of vertical development as indicated by radar measurements. The data in Table 1 provided the best combination of all these factors among the storms sampled in 1963, although these data are not completely satisfactory in all respects.

Because of limitation of the number of strontium analyses to 400, selections were more restrictive than in the selections for beta analyses. Strontium analyses were limited to those storms sampled in conjunction with Project Springfield and to storms in which adequate radar data were obtained with both RHI and PPI

TABLE 1

NUMBER OF GROSS BETA AND STRONTIUM SAMPLES ANALYSED IN 1963

	Gross Beta Analyses			Strontium Analyses		
	Time Samplers			Time Samplers		
Storm Date	Number of Stations	Number of Samples	Number of Total Storm Samples	Number of Stations	Number of Samples	Number of Total Storm Samples
3/4	1	14				
3/5	1	6				
3/8	1	4				
3/18	1	9				
3/25-26	1	4	6			
3/11	1	4				
3/30-31	1	8	1			
3/16			5			
4/16-17	10	21	4	5	14	9
4/19	3	12	7	5	18	9
4/22	2	11	13	7	30	5
4/29	5	30				
4/30	4	14	1			
5 A	5	21	1	6	27	
5/12	1	8				
5/16	1	6				
5/27-28	2	20	29			
6/7	1	4				
6/10	13	56		13	63	6
6/13	2	14	9	11	62	
6/19	2	14	4	9	42	6
7/1	5	14	13	7	38	8
7/6	8	14	20			
7/13	7	103	24	1	32	19
7/19-20	4	42	18			12:
7/31	5	51	14			
8/6	5	45	5			
8/8	5	44	7			
8/12	5	30	3			
8/19	3	43	7			
8/28	6	46	11			
9/2	4	23	12			
Total	115	815	214	64	326	74

radar. Eight storms were sampled during the spring and summer 1963 in which both RHI and PPI data were considered adequate for detailed analyses of the horizontal and vertical structure of storms. Mechanical problems with the TPS-10(RHI) set were primarily responsible for this limited number. Partial to complete coverage of all storms from April to September listed in Table 1 was achieved with the CPS-9 radar.

In processing of the storm data, radar echo maps have been plotted at intervals of 5 minutes to 30 minutes in each storm, depending upon storm characteristics and operational procedures during the storm. Copying of the necessary data from the radar film has proven to be a major task. Maps have been drawn for both the PPI and RHI presentations, whenever available. From these maps, the areal extent, movement, and vertical structure of storm echoes were determined as they moved across the rainwater sampling network. Maps have been completed for 20 storms which include 8 storms under observation by both the TPS-10 and CPS-9 radars, and 12 others in which CPS-9 coverage was achieved. In part of these 12 storms with CPS-9 coverage, the set was periodically operated on an antenna tilt program, so that some information on cloud tops is available for these storms also. At the present time, the radar data are being used in conjunction with data from radiochemical analyses and meteorological data in mesoscale case studies of the storms.

With the assistance of the Water Survey's Statistical Unit, a program was devised for the IBM-7090 computer to facilitate the analyses of radar-indicated cloud tops over the rainwater sampling network of 6000 square miles. Through use of this program, machine plotting of maps of cloud tops can be achieved at 1-mile intervals from cloud top data taken from the TPS-10 radar film.

An example of an analysed map from the storm of June 10 is shown in Figure 4. The isolines connect points of equivalent cloud tops. The echo top contours are drawn only for echoes extending above 10,000 feet. The CPS-9 echo outline at the same time is shown also in Figure 4, along with the location of the rainwater samplers. The CPS-9 echo is an integration of the precipitating cloud mass in the lower several thousand feet of the atmosphere, and should not, therefore, have the same areal extent as the radar indicated cloud tops. Figure 4 illustrates well the spreading out of the cloud system aloft over a convective storm system, particularly in the direction of movement. In this case, the echoes are part of a pre-frontal squall line moving from the WNW. Mapped data such as shown in Figure 4 are useful in numerous aspects of radioactivity studies, but are particularly applicable in efforts to ascertain relations between cloud height and radioactive rainout on the network.

Gross beta analyses have been completed for all 1029 samples listed in Table 1, and various statistical analyses of the data

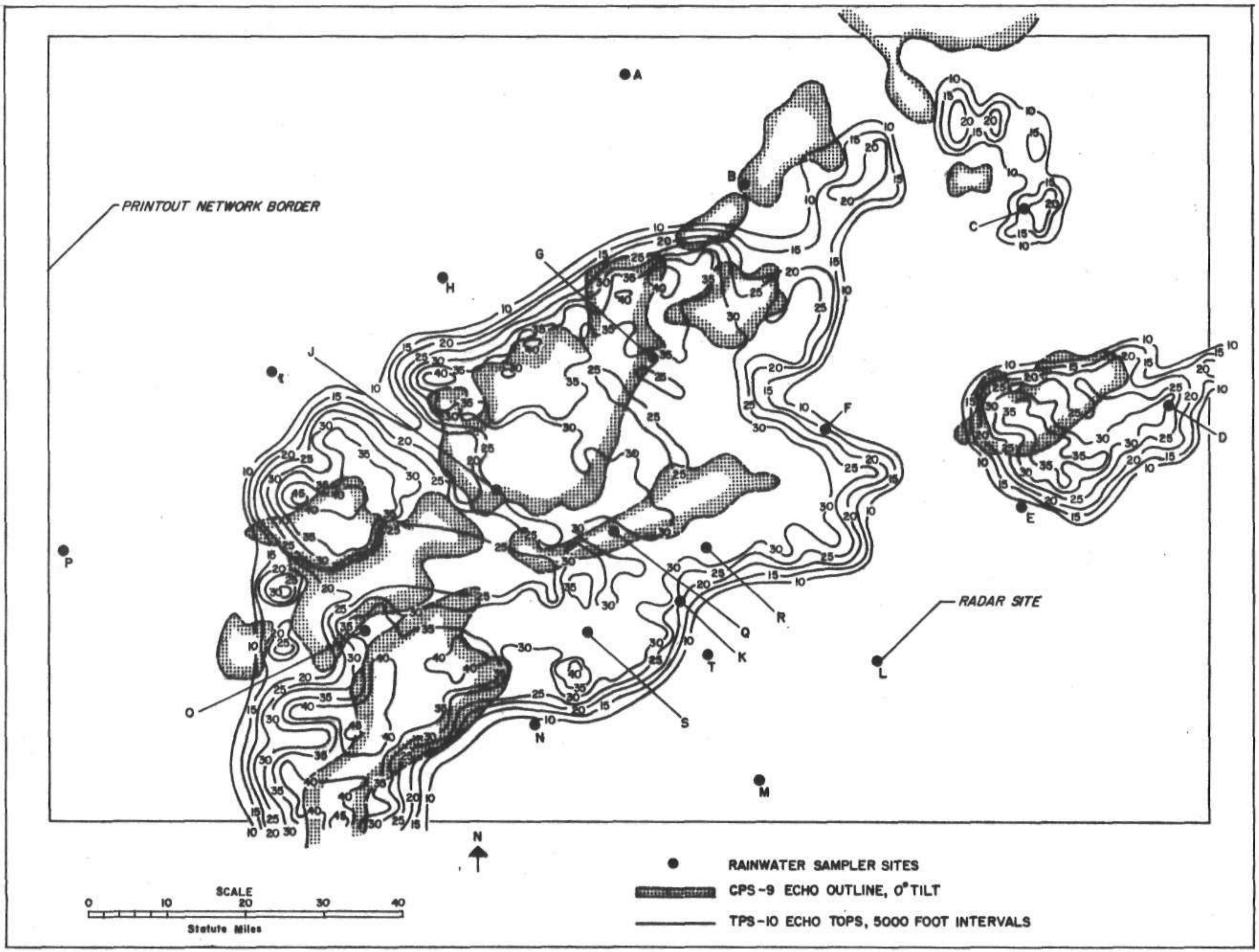


FIG. 4 RADAR PRESENTATION AT 1502 CST ON JUNE 10, 1963.

completed. Results of these analyses are discussed in a later section of this report. Also, various rainfall analyses made in conjunction with the radioactivity studies have been completed. In fact, all tabulation and routine analyses have been completed on the 1963 data, except for those which must await completion of the strontium analyses. The major tasks to be completed are the mesoscale case studies of 1963 storms and statistical analyses of the 1963 strontium data.

BETA DISTRIBUTION CHARACTERISTICS

An investigation was made of the distribution characteristics of beta concentrations during 1963 storms through use of data from the automatic time samplers. Analyses were made of the variation of beta concentration with (1) the rainfall volume distribution and (2) the rainfall time distribution in storms. The beta distribution patterns were then correlated with four rainfall factors; these include total storm rainfall, rainfall duration, rainfall rate, and rain type. Efforts were made also to relate the distribution patterns of beta concentration to several types of synoptic storms.

Method of Analyses

Analyses have been restricted to those storms in which at least four rainwater samples were obtained to define the distribution pattern of beta concentration. Furthermore, it has been necessary to limit the analyses to storms in which samples were obtained throughout the life of a storm. This requirement eliminated a considerable portion of the 1963 storm data from the analyses because of incomplete sampling that resulted from operational problems with the time samplers, discussed in a preceding section, and from heavy storms in which the 12 sample bottles were not sufficient to sample completely from the beginning to the end of the rainfall period. However, despite the restrictions, 87 cases from 29 storms were available from 1963 field operations for the study.

A normalizing procedure was employed in the construction of beta distribution curves for the 1963 storms to permit correlations between stations within a particular storm and from one storm to another. In this procedure, the beta concentration in each sample collected at a sampling station within a particular storm was expressed as a ratio to the average beta concentration for the storm. These ratios were then plotted against (1) cumulative percent of storm rainfall, (rain volume) and (2) cumulative percent of storm duration, as shown in the examples of

Figure 5 for a squall line passage on June 10 at station R. These curves provide a measure of the beta concentration variation with the time and volume distributions of rainfall. Discussion will be restricted to the volume distributions in this progress report, since similar conclusions were reached from both types of analyses.

Also, distribution curves of rainfall rate were constructed for each of the 87 cases through use of the normalizing method used with the beta distributions. In the construction of these curves, the ratio of the sample rainfall rate to the average rainfall rate for the entire storm was plotted against cumulative percent of storm rainfall, as illustrated in Figure 5c. The sample rainfall rate corresponds to the average rate during the collection of a beta sample. These rainfall rate curves provide a means for determining whether progressive changes in beta concentration within a storm are related to corresponding changes in rainfall rate, and whether particular types of beta distribution patterns are related to particular types of rainfall rate distribution patterns,.

Use of the distribution curves in this study is illustrated in Figure 5. Thus, Figure 5 shows that the rainfall rate increased rapidly as the squall line reached Station R and peaked at a rate of approximately 2.35 in./hr. at the time that approximately 50 percent of the rain had occurred. However, other calculations show that this peak occurred early in the storm period when only approximately 9 percent of the total storm time had ensued. The rate decreased rapidly and only light rain fell in the last 20-25 percent of the storm period. Figure 5a shows that the beta concentration decreased rapidly from its major peak at the start of the storm to a minimum when approximately 70 percent of the rain had occurred. At that time, 20 percent of the storm period had passed. A secondary peak occurred at the rear of the storm system in light rain from the stratified cloud deck behind a line of thunderstorms. The rainfall rate curve indicated the line consisted of one major burst at station R, and Figures 5a and 5b show a pronounced minimum in the beta concentration. corresponding to this rainfall rate peak. The beta minimum lags the rainfall rate peak, and occurs about 20 percent (0.05") later with respect to rainfall volume.

As indicated earlier, there were 87 cases available for analyses from the 1963 field operations. Over 90 percent of these cases involved convective rainfall. Distribution curves were determined for each case from plots of cumulative percent of" total storm rainfall against beta concentration ratio. From these curves, values were tabulated at intervals of 5 to 10 percent of the cumulative percent of storm rainfall, as illustrated for the storm of June 10 in Table 2. The curves were also classified by total storm rainfall, rain duration, average rainfall rate, rain type, synoptic type, and shape of the beta distribution curve or

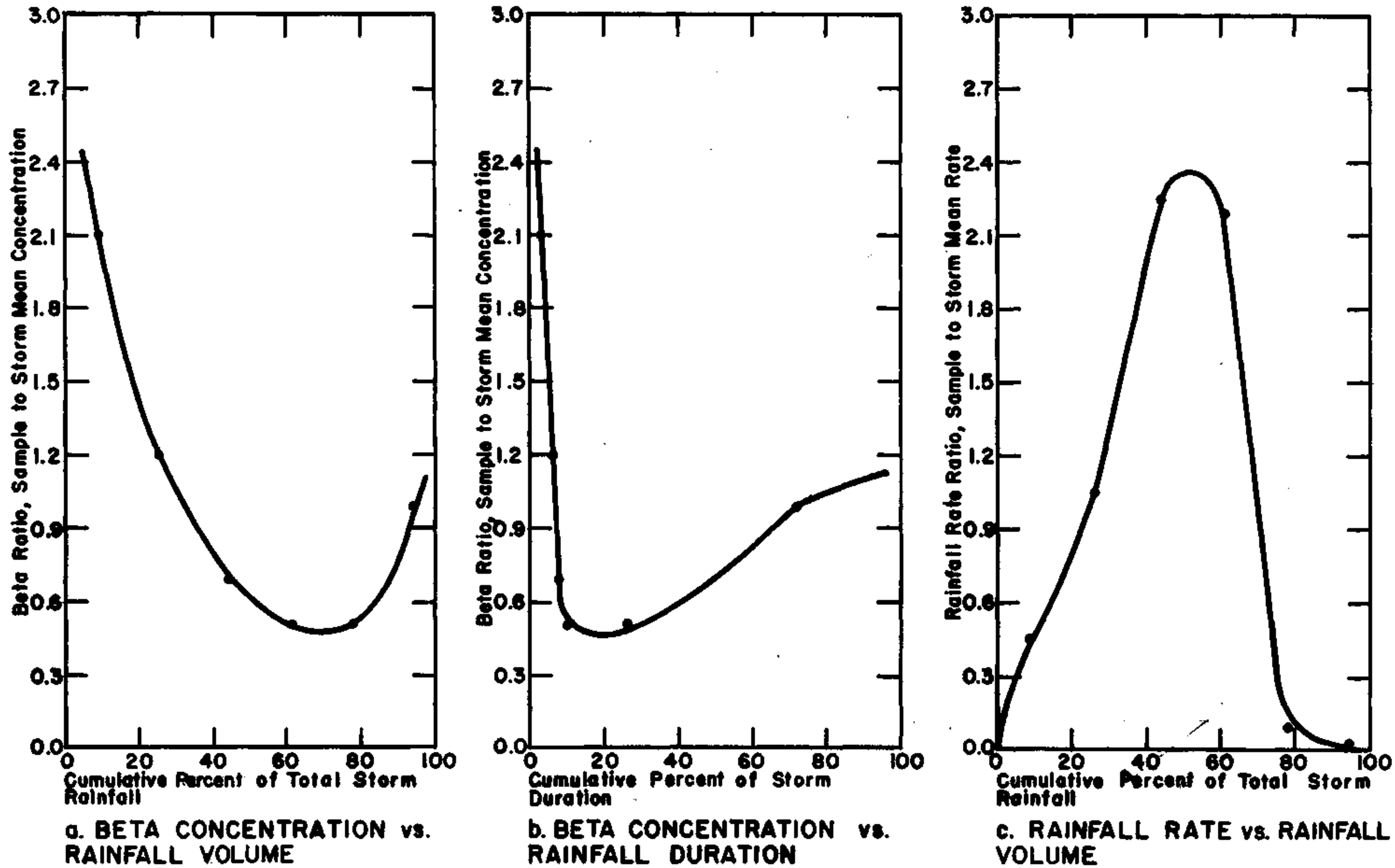


FIG.5 EXAMPLES OF DISTRIBUTION CURVES AT STATION R IN STORM OF JUNE 10, 1963

TABLE 2

BETA CONCENTRATION - RAINFALL VOLUME DISTRIBUTION
SUMMARY ON JUNE 10, 1963

Station	Total Rain (in.)	Rain Duration (hrs.)	Average Rain Rate (in./hr.)	Rain Type	Synoptic (1) Type	Beta Shape	Storm (2) Average Beta
E	0.39	1.1	1.03	TRW, R	CFSL	A	5123
G	0.15	1.5	0.14	" "	"	C	9533
I	0.23	1.5	0.45	" "	"	C	2250
K	0.20	0.9	1.07	" "	"	A	7447
M	0.50	1.6	0.50	" "	"	A	4736
N	0.40	1.9	1.34	" "	"	A	3462
R	0.23	1.3	1.12	" "	"	A	8833
T	0.20	0.1+	1.50	TRW	"	A	4225

(1) CPSL - Cold Front Squall Line

(2) Beta concentration in micro microcuries per liter

Beta Ratio for Given Cumulative Percent of Storm Rainfall

Station	5	10	20	30	40	50	60	70	80	90	95
E	2.6	1.4	0.7	0.5	0.4	0.4	0.5	0.6	0.9	1.4	1.8
G	-	0.7	0.9	1.0	1.1	1.2	1.2	1.1	1.1	1.0	0.9
I	-	0.7	0.9	1.0	1.1	1.2	1.2	1.1	1.0	0.9	0.8
K	2.2	1.5	1.0	0.9	0.8	0.8	0.7	0.6	0.9	1.3	1.5
M	1.7	1.3	1.0	0.9	0.8	0.7	0.8	0.9	1.0	1.1	1.1
N	2.8	1.8	1.2	0.8	0.7	0.6	0.4	0.4	0.8	1.4	2.0
R	2.4	2.0	1.4	1.0	0.8	0.6	0.5	0.5	0.6	0.8	1.0
T	4.5	2.2	1.4	0.7	0.6	0.6	0.7	0.8	0.9	1.0	1.0

storm profile (Table 2). These tabulations then provided the basic data for investigation of possible relationships between the beta storm profile and various meteorological factors.

Average rainfall rate in Table 2 was calculated by dividing the average of the individual sample rates by the number of samples, rather than by the standard method of dividing total storm amount by storm duration. This was done because the distribution curves were determined from the individual samples, and it appeared that in many cases, such, as the storm of June 10, the rate relationship to beta concentration would be masked by the excessive influence that a small amount of rainfall spread over a relatively long time (usually at the end of the storm) might have on the rainfall rate determination. For example, at station R on June 10 (Fig. 5) approximately 78 percent of the rain occurred in the first 26 percent of the storm time, and 5 of the 6 rainwater samples that determine the distribution curve were collected in this short period during relatively heavy rain intensities. In this case, the mean rate calculated in the usual manner would be only 0.18 in./hr. compared to 1.12 in./hr. calculated by the sample averaging method.

Beta Distribution Types

Examination of the beta distribution curves showed that they could be grouped into four major and three minor types. The four major types account for 89 percent of the 87 cases used in this study. Mean distribution curves for each of the four major types are shown in Figure 6 (solid lines). Type A was found to occur in 45 percent of the 87 storm samples. Type B occurred 19 times, or in 22 percent of the cases. Type C was found 11 times and Type D occurred 8 times. Specific examples of the major types of beta distribution are shown in Figure 7.

The three minor types accounted for only 10 of the 87 cases. Type E is intermediate between types B and D; the beta concentration decreases rapidly in the early part of a storm and then becomes relatively steady throughout the remainder of the rain period. Type F is the opposite of Type B, that is, the beta concentration shows a general increase in activity from beginning to end of a storm period. Type G is similar to Type F, except that a minor peak occurs in the distribution in the early part of the storm, similar to the secondary peak in the latter part of the storm shown by Type D.

Table 3 shows the frequency distribution of the location of the beta concentration minimum with respect to cumulative percent of storm rainfall in Type A storms. The beta minimum occurred most frequently when 61 to 80 percent of the total storm rainfall had occurred.

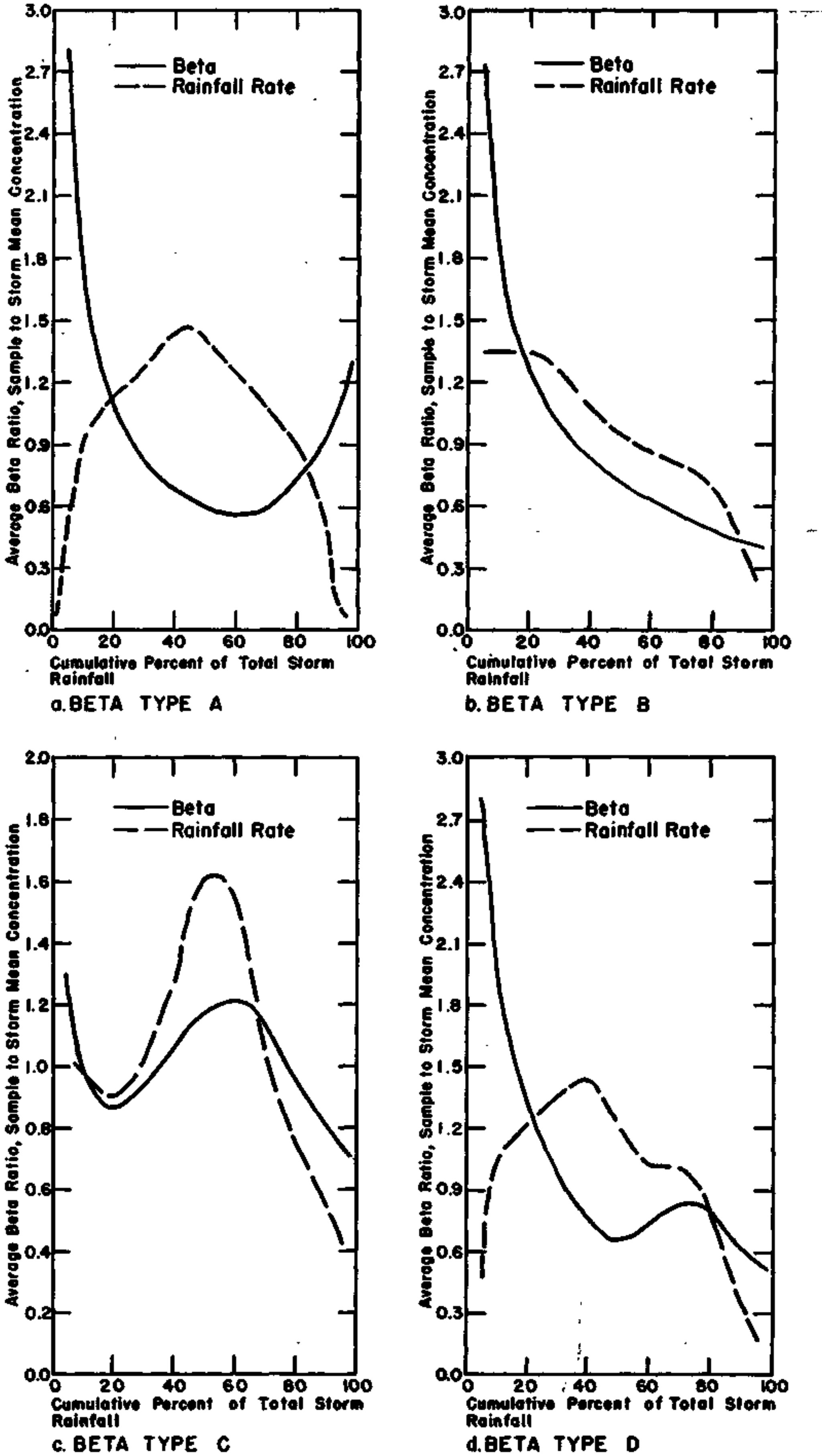


FIG.6 AVERAGE RELATIONS FOR THE FOUR MAJOR DISTRIBUTION PATTERNS OF BETA CONCENTRATION IN 1963 STORMS

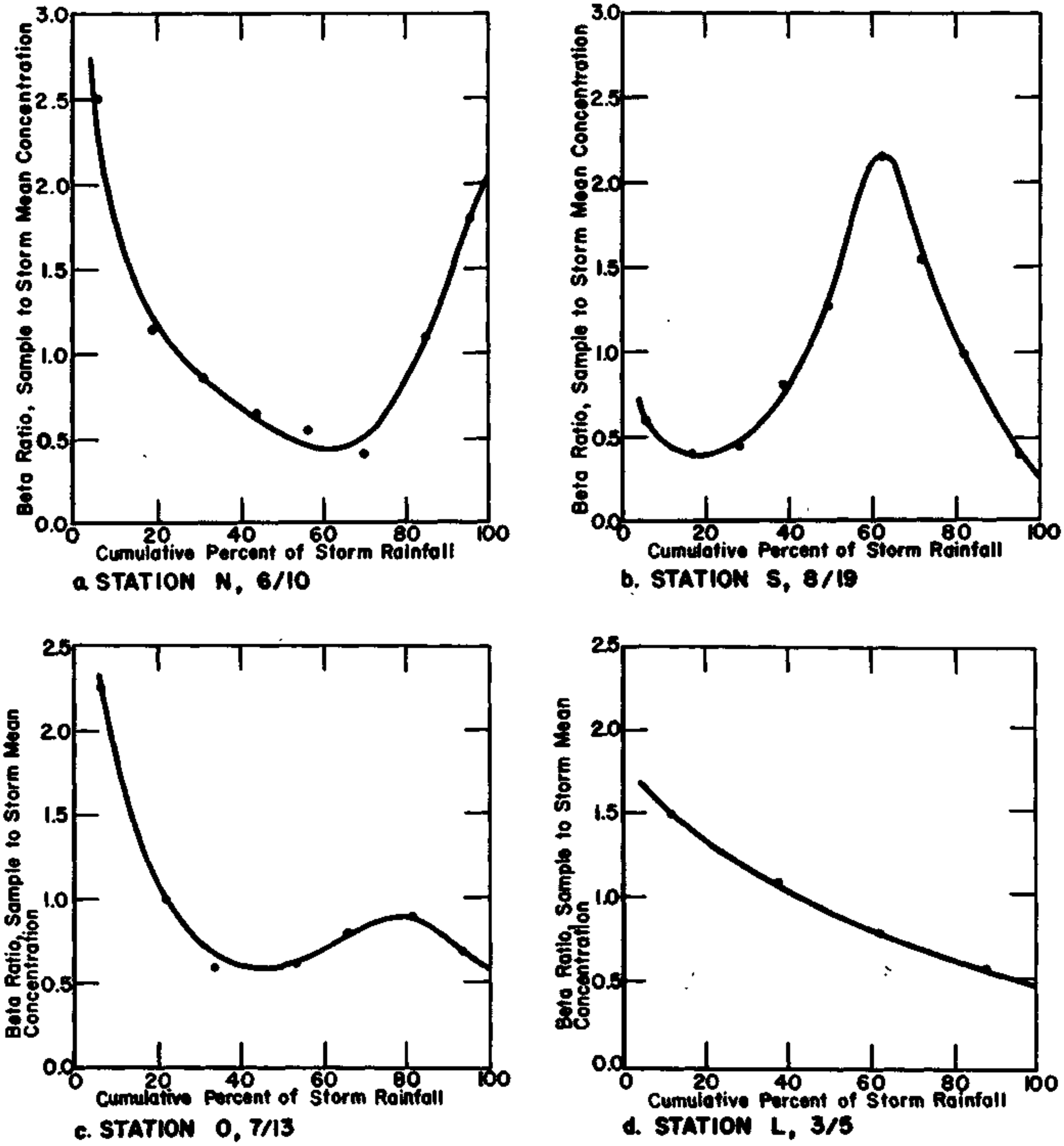


FIG.7 EXAMPLES OF MAJOR BETA DISTRIBUTION PATTERNS IN STORM RAINFALL

TABLE 3

LOCATION OP BETA CONCENTRATION MINIMUM IN BETA TYPE A STORMS IN 1963

Cumulative percent of Storm Rainfall	Number of Cases
21-30	3
31-40	7
41-50	4
51-60	3
61-70	12
71-80	9
81-90	1
Total	39

Relation Between Beta Distribution and Rainfall Factors

The next step taken, in the study was to investigate the effect of various rainfall factors upon the shape of the distribution curves of beta concentration and upon the magnitude of the values along these curves. The general effect of total storm rainfall was evaluated first by grouping all 87 cases into the following classes: 0.1l-0.20 inch, 0.21-0.30 inch, 0.31-0.40 inch, 0.41-0.50 inch, 0.5l-0.75 inch, 0.76-1.00 inch, and over 1.00 inch. The range of the classes was dictated by the number of cases in each intervale Average ratios were calculated for each class at intervals of 10 percent along the cumulative rainfall axis. This analysis indicated that the magnitude of total storm rainfall does not strongly influence the characteristics of the beta concentration profile throughout a storm. It was found that average ratio differences between rainfall classes were small, in general, and that they demonstrated no distinct trend with increasing storm rainfall. The results are illustrated by the summary in Table 4 at selected values of cumulative percent of total storm rainfall.

Next, analyses similar to that described for total storm rainfall were performed by grouping the 87 cases by rainfall duration, average rainfall rate, and rainfall type. Results in each analysis were similar to those obtained in the analysis of total storm rainfall; that is, no evidence was found that the characteristics of the beta concentration distribution at a specific point in a storm are determined uniquely by a single

TABLE 4

EFFECT OP TOTAL STORM RAINFALL ON BETA DISTRIBUTION PATTERN

Cumulative Percent of Storm Rainfall	Average Beta Ratio for Given Magnitude of Total Storm Rainfall (in.) 0.11-0.20	0.21-0.30	0.31-0.40	0.41-0.50	0.5l-0.75	0.76-1.00
10	l.6	1.8	1.5	1.4	1.6	1.2
30	6.9	1.0	0.8	0.9	0.8	0.9
50	0.8	0.8	0.8	0.8	0.7	0.7
70	0.7	0.9	0.7	0.7	0.6	0.8
90	1.0	0.8	0.9	0.7	0.6	0.9

rainfall parameter observed at the same point. These results do not preclude the possibility of a relatively strong areal relation between the patterns of beta activity and rainfall. This possibility will be discussed in a later section of this report.

The 39 cases of Type A beta distribution were examined next with regard to effects of total storm rainfall, average rainfall rate, and rainfall duration. It was considered possible that restriction of the analysis to a particular type of beta storm profile might reveal relationships with the rainfall parameters that had been masked by combining all types, as was done in the preceding analyses. However, results were the same; no pronounced trend was found for the shape or magnitude of the Type A distribution to vary with increasing storm rainfall, rainfall duration, or average "rainfall rate in storms. There was some indication that the average beta ratios decrease with increasing storm duration, but the change was small and may have resulted from sampling vagaries.

Relation Between Beta Distribution and Synoptic Weather Types

The frequency distribution of the 87 storm samples was determined with respect to synoptic type associated with the rainfall. Four basic types of synoptic storms were used; these included storms associated with cold fronts, warm fronts, unstable air masses, and low center passages. Cold frontal rainfall included that associated with both pre-frontal squall lines and with frontal passages. Warm frontal rainfall included precipitation occurring with stationary fronts located south of the sampling network, in addition to rain associated with the approach and passage of warm fronts. Low-center rainfall included all storms in which a low center passed through or near the network, usually accompanied by warm and/or cold front passages also. Air mass precipitation included rainfall occurring in the absence of fronts within several hundred miles, and in 1963 was confined to storms occurring in mT air masses.

The 1963 frequency distribution, expressed in percent of total cases, is shown in column 2 of Table 5. The frequency of warm frontal rains was greatly above normal in 1963, whereas the cold frontal and air mass types were much below normal. However, the abnormality does not prevent investigation of the possible relationship between synoptic type and beta distribution type. In columns 3-7 of Table 5, the percentage distributions of the cases in each of the four major types of beta storm distributions are shown. Column 7 combines Types B and D, since D is similar to B except for interruption of the downward trend in beta concentration throughout a storm by a secondary peak in the latter part of the storm period (Fig. 6).

Table 5 indicates an above normal percentage of cold fronts associated with Type A distributions. However, this departure of seven percent (31 to 24) is not great for a sample of 39 cases, and could be largely the result of the vagaries of sampling. The most outstanding departures from the average distribution in Table 5 are those for Types B and D. These two types were strongly biased toward warm front occurrences in 1963, and, conversely, were associated infrequently with cold fronts. There were 19 and 8 cases, respectively, for Types B and D, providing a total of 27 cases upon which the results in column 7 of Table 5 are based. Type C, which has a pronounced mid-storm peak (Fig. 6), shows positive departures from the 1963 averages for cold fronts, but the 11 samples are insufficient to arrive at reliable conclusions, except that the 1963 data do show that this type of distribution is not restricted to a particular synoptic type.

TABLE 5

COMPARISON OP BETA CONCENTRATION DISTRIBUTIONS
WITH SYNOPTIC WEATHER TYPES

Synoptic Type	Percent of Total Synoptic Cases	Percent of each Synoptic Type with Given Beta Distribution Type				
		Type A	Type B	Type C	Type D	Types B+D
Cold Front	24	31	5	36	12	7
Warm Front	54	46	68	55	88	74
Air Mass	10	10	5	9	0	4
Low Center	12	13	22	0	0	15

Table 6 shows the association of beta distribution type with synoptic type expressed in another form. Prom this table, it appears that cold frontal precipitation has a Type A beta distribution most frequently. Warm fronts also show a maximum with Type A distributions, but Type B follows closely in frequency of occurrence. Insufficient observations have been obtained with the other two synoptic types for the statistics to have much meaning.

TABLE 6

DISTRIBUTION OP BETA TYPES WITH POUR SYNOPTIC TYPES

Synoptic Type	Number of Cases	Number of Cases for Given Beta Type						
		A	B	C	D	E	P	G
Cold Front	21	12	1	4	1	1	1	1
Warm Front	47	18	13	6	7	0	2	1
Air Mass	9	4	1	1	0	3	0	0
Low Center	10	5	4	0	0	0	0	1

Inspection of the 1963 data indicates that the Type A distribution, in the case of cold fronts, is produced by an increase in the beta concentration in the light steady rain falling from the stratiform cloud deck to the rear of pre-frontal or frontal squall lines. In the 12 cases of Type A with cold fronts it was found that 50 percent of the total storm time was used, on the average, in collecting the last sample in the series through the rainstorm. The ratio of beta concentration in the last sample to the concentration in the preceding sample averaged 1.9 for the 12 cases. These statistics emphasize the change in rainfall characteristics occurring near the end of these storms. Evaporation from raindrops in the drier air to the rear of a squall line or cold front may contribute to the increased beta concentration in the last sample, but it also is likely that the concentration increase is partially caused by air from high levels being brought down to the surface in downdrafts in rear of the convective system. The number of samples in the storms used in this analysis varied from 4 to 12 depending upon the intensity and duration of the storm.

Type A distributions associated with the other synoptic types were investigated also, and it was found that, on the average, about 34 percent of the storm time was used in collection of the last rainwater sample in a series. Thus, the same tendency was found with all synoptic types producing Type A distributions, but the tendency was stronger with cold front precipitation.

Investigation of Type B distributions to date has not revealed any specific cause of their shape or characteristics, except that they are predominantly associated with warm fronts or low pressure systems.

Rainfall Rate Distributions

Rainfall rate was classified according to type of storm distribution in the same manner as the beta distributions. Analyses of the data resulted in division of rainfall rate distributions into the following seven types which are illustrated in Figure 8.

(a) Type 1 — a single-peaked profile through the storm resulting from a gradual increase of rainfall rate to a maximum in the storm system, often near the mid-point of the storm with respect to rainfall volume, then a gradual decrease with the rate of decrease becoming less near the end of the storm.

(b) Type 1S -- maximum rate at the start of the storm with gradual decrease throughout the rainfall period.

(c) Type 1SF -- maximum rate at the start of the storm but continuing nearly constant for a considerable period, followed by a general decrease, that is often rapid.

(d) Type 1E -- gradual increase in rainfall rate to a maximum near the end of the storm.

(e) Type 1P -- relatively high rate at the start of the storm followed by an appreciable decrease and then a major peak in the eentral part of the storm.

(f) Type 2 -- two distinct peaks in the rate profile, with the first peak most frequently the major peak.

(g) Type 3 -- three distinct peaks in the rate profile through a storm.

The frequency distribution of the rainfall rate types is given in Table 7. Type 1 occurred most frequently, 37 times or in 43 percent of the storms. Type 2 ranked second with 25 cases and 29 percent of the total occurrences. With regard to Type 1, it was found that the rainfall rate peak had its median value at 50 percent, that is, the peak was reached when 50 percent of the rain had fallen. In 81 percent of the cases, the Type 1 peak occurred when 35 to 64 percent of the rain had fallen.

Analyses were then made to determine (1) whether these rate profiles (distribution patterns) were correlated with the total volume of storm rainfall, the rainfall duration, and the average rainfall rate, and (2) whether particular types of beta distributions

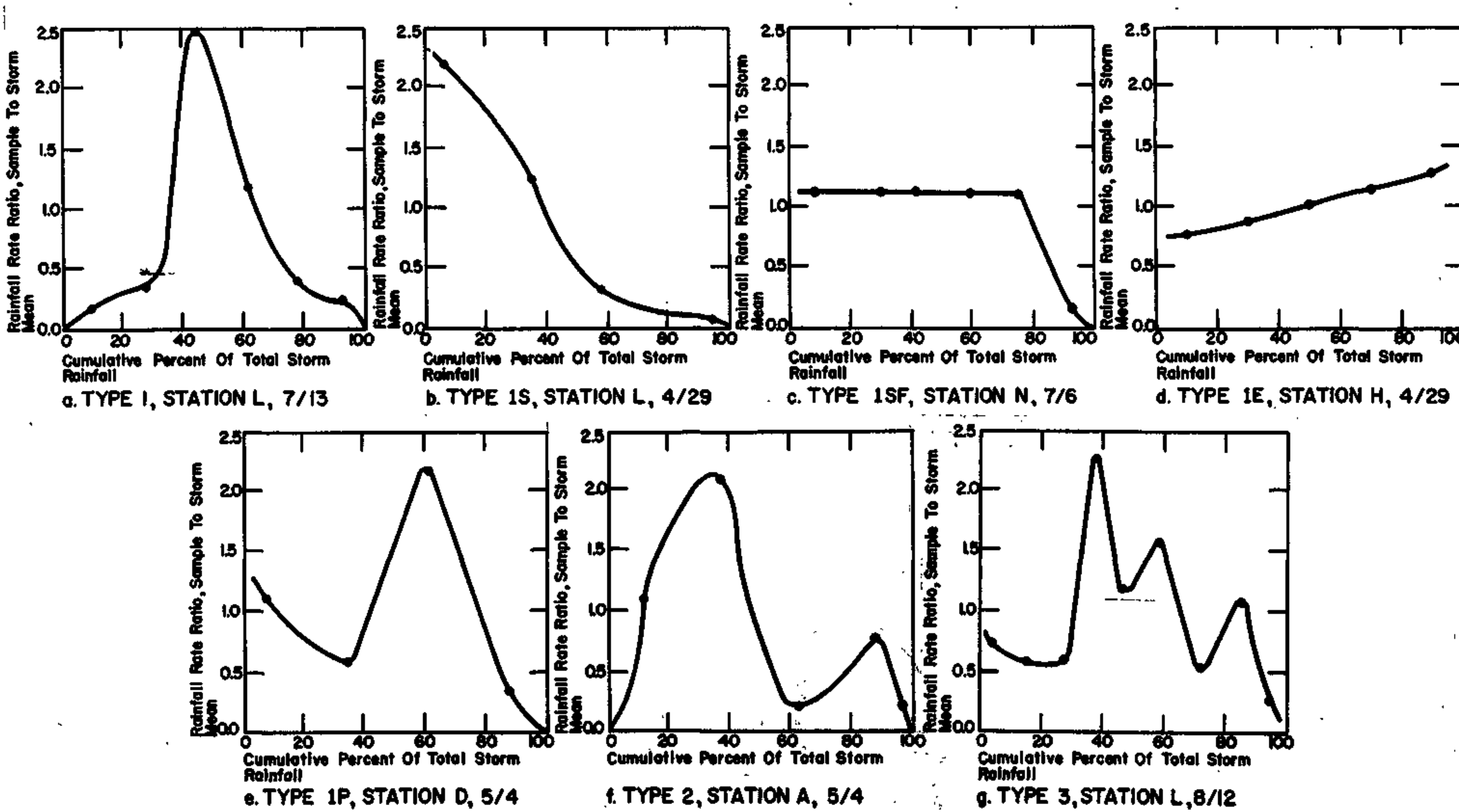


FIG. 8 EXAMPLES OF VARIOUS TYPES OF RAINFALL RATE DISTRIBUTIONS.

tended to be associated with particular types of rainfall rate distributions in storms. In the investigation of (1) above, the 87 cases of storm time samples obtained in 1963 were grouped by total storm rainfall, rainfall duration, and average rainfall rate and average distribution curves of rainfall rate calculated for each group. Results of this analysis indicated no strong trend for the rainfall rate profile to be determined by the other rainfall factors tested.

TABLE 7

FREQUENCY DISTRIBUTION OP RAINFALL RATE TYPES IN 1963

Type	Number of Gases
1	37
1S	7
1SF	7
1E	3
1P	5
2	25
3	3

Comparison Between Beta and Rainfall Rate Distributions

Next, comparisons were made between the types of beta and rainfall rate distributions. It was found that Type A, the most common beta distribution, occurred most frequently with rainfall rate Type 1. Of 39 beta Type A storms, 22 or 56 percent had rainfall rate Type 1 associated with them. Second in importance was rate Type 2 with 6 occurrences.

Rainfall rate Type 2 was associated most frequently with beta Type B, with 9 occurrences out of a total of 19 Type B storms. Of 11 cases of beta Type C storms, 6 had rainfall rate Type 2 distributions, that is, storms with two distinct bursts within the rain periodo Four of the 8 cases of beta Type D storms occurred in conjunction with rate Type 1, the single burst type of storm.

Further analyses of beta Type A distributions revealed a strong tendency for the minimum in the beta curve to be associated with a major peak in the rainfall rate distribution, regardless of the rate type, with the beta minimum lagging the rainfall rate maximum somewhat. This tendency is reflected in the average curves of beta Type A and the average rainfall rate curve for these 39 cases shown in Figure 6, Thus, on the average, the beta minimum was found to occur at 65 percent or after an additional 20 percent of the total rain had fallen following the occurrence of the major peak in the rainfall rate distribution at 45 percent.

The major rainfall rate peak in a storm is likely to contain rainfall originating in the region in which maximum vertical development of the cloud system took place earlier. Assuming a uniform distribution of radioactive debris in the atmosphere, equal depth of convective clouds throughout a storm, and a similar raindrop size distribution throughout the storm, the beta concentration would tend to minimize in conjunction with the peak rainfall intensity, since there would be a greater volume of rainwater to dilute the radioactivity in the atmosphere. However, the minimum beta concentration would tend to be displaced from the rainfall rate maximum, if the cloud system in the region in which the maximum rate developed had towered to greater heights than the rest of the storm cloud system thereby becoming exposed to high-level sources of greater radioactivity. The displacement of the rainfall rate peak from the beta Type A minimum in Figure 6 indicates the frequent occurrence of the situation described above.

No reversal of the decreasing trend in beta concentration occurs with beta Type A as the rainfall rate maximizes, but, the rate of decrease appears to proceed at a slower rate. A reversal would be expected, if a high-level source of rich radioactivity was penetrated. This suggests that the Type A distributions may be representative of distributions in mature convective systems in which the high-level source of radioactivity has been diluted - somewhat by penetration at an earlier stage in the storm. Type C, discussed later, appears representative of the distribution to be expected with the initial stratospheric penetration by a given convective system. The lagging of the beta minimum from the rainfall rate maximum with the beta Type A distributions is associated apparently with rainfall which follows that produced during the maximum height development of the eonvective storm, and which, therefore, is more diluted with respect to radioactive debris. The increase in beta concentration following the minimum may then result from increased evaporation of falling raindrops in the rear portions of the storm, an increased number of available particulates per unit volume of cloud water in the latter stages of the storm, and the downward transfer of stratospheric air in the rear portion of the storm system.

The series of events hypothesized above satisfy the observed relationships between beta Type A distributions and the distribution of rainfall rate in the majority of the cases. However, a similar explanation does not seem to fit the beta Type B distributions, the second most common beta type. In this case, the beta concentration reaches a peak at or near the start of a storm period and decreases throughout the storm (Fig. 6). As indicated earlier, the Type 2 rainfall rate distribution was dominant with the beta Type B distributions. In general, the major rate peak with the Type B storms occurred considerably earlier in the rain period than it did with the Type A storms and was not associated with a distinct change in beta concentration, the beta concentration continuing to decrease prior to and following the rate peak. This sequence of events indicates that changes in rainfall rate had little influence on the beta concentration profile in Type B storms, and that the beta concentration was decreasing as the result of cleansing of the atmosphere as the rainstorm progressed. This, in turn, implies that the rainstorm was exposed to a generally uniform distribution of radioactive particulates throughout its life, and that the cloud system associated with the rainfall rate peak did not reach sufficient heights to become contaminated to any large degree from the stratospheric reservoir of debris. The beta Type B distributions were biased strongly toward association with warm frontal rain. Such rain tends to be more widespread and more continuous than cold front and air mass types, and, therefore, more conducive to a general dilution of the available radioactive debris with time in a storm system. Regardless of the cause, however, the beta Type B distribution results from rainstorm conditions that produce gradual dilution of the beta supply, and it is a type of distribution that occurs frequently in convective storms.

Beta Type G distributions are the opposite of beta Type A in that they show a peak instead of a minimum (Fig. 6) in beta concentration near the middle part of the storm. Examination of the rainfall rate distributions associated with Type C storms indicated a strong tendency for a major peak in the inner portions of the storm, A median peak location at 53 percent of the cumulative rainfall volume was found for the 11 cases (Fig. 6), and, in 10 of the 11 storms, the major rate peak occurred in the range from 35 to 70 percent. Figure 6 shows that the beta peak lags slightly behind the rainfall rate peak, on the average, in beta Type C storms. The major beta peak in the middle portions of a convective storm appears to be associated with a deep vertical development of the cloud deck into the stratospheric reservoir of radioactive particulates. As suggested earlier, Type G distributions may represent the initial stratospheric penetration by a convective storm, whereas some time later the same storm could produce a beta Type A distribution in passing over another station. This sequence of events appears to have occurred in the storm of June 10, 1963. On that date, a squall line developed near the western border of the time sampler network (Fig. 1) and moved ESE across the network. At station I near the western edge of the network, a beta Type C distribution was recorded, whereas all time sampler stations in the central and eastern parts of the network recorded Type A distributions.

Beta Type D (Fig. 6) shows a minor peak in the beta concentra= tion following a rapid decrease in concentration in the early portions of the storm. On the average, this peak was found to occur after about 75 percent of the rain had occurred. Examination of the rainfall rate distributions associated with the eight cases of beta Type D distributions showed no strong tendency for a peak or valley in the distribution corresponding to the beta peak. Seven of the cases occurred with warm fronts, and the rain was associated with overrunning of a front to the south or southwest. In one of the eight cases a major peak in the rainfall rate distribution was associated with the secondary beta peak, and in two other cases a minor peak in the rainfall rate curve accompanied the secondary beta peak. In the other five cases, a single rate peak occurred in the first half of the rainfall period with respect to cumulative volume of rainfall, that is, before half of the rain had occurred. At this time, no satisfactory explanation for the secondary peak has been found from comparison of the beta and rainfall rate distributions.

Analyses of 1963 storms indicated that more than one type of beta distribution occurred in a particular storm at the various stations in the rainwater network, although a particular type generally dominated. For example, beta Type A distributions occurred at six of the eight stations for which time samples were obtained on June 10 (Table 2), and beta Type C profiles were recorded at the other two stations. It is likely that the characteristics of the beta distribution are affected by the position of a station with respect to a particular RW or TRW, and an investigation of this factor is presently underway through use of radar data obtained with part of the 87 storm samples.

BETA CONCENTRATION AT START AND END OF STORMS

Total Storm Relations

Examination of time samples from the rainwater network during 1963 has indicated a strong trend for a peak in the beta concentration at the start of storms and a lesser trend for an increase in concentration at the end of storms. Table 8 provides a quantitative measure of these trends in 12 storms in which time samples were collected at three or more stations. In this table, the average ratio of the beta concentration in the first sample (S_1) to the concentration in the second (S_2) is shown for each storm in column 2. The following columns show the average ratio of the concentration in the last to the next to last sample (L/L-1), the ratio of the initial concentration to the storm average concentration (S_1/A) and median concentration (S_1/M), and the ratio of the last sample's concentration to the storm average (L/A) and median (L/M). The data in Table 8 are for entire storm periods that may have included more than one burst or shower. The samples contained approximately equal volumes of rainfall, which usually ranged from 0.01* to 0.06 inch depending upon the wind velocity at the sampling sites.

TABLE 8

BETA CONCENTRATION AT START AND END OP 1963 STORMS

Date	S_l*/S_2	L*/L-l	$S_1/A*$	$S_1/M*$	L/A	L/M
l*/29	1.6	0.8	1.6	1.8	0.7	0.7
5/1*	2.0	1.1	1.8	2.1	0.7	1.0
6/10	2.1	2.0	1.7	1.7	1.2	1.4
7/1	2.6	1.6	2.2	2.6	0.8	1.0
7/6	2.1	1.0	3.3	4.8	0.4	0.6
7/13 (AM)	2.5	2.0	3.2	5.8	0.6	0.8
7/13 (PM)	1.7	1.4	1.8	2.4	0.9	1.1
7/31	1.4	1.0	1.4	1.6	0.9	0.9
8/6	1.3	1.1	2.1	2.7	0.8	1.0
8/12	2.9	1.6	2.2	3.4	1.1	1.8
8/28	1.5	1.1	1.3	1.5	0.9	0.9
9/2	2.0	0.8	2.3	2.2	0.5	0.6

S-start, L-last, A-average, M-median

Combining the data in Table 8 with that from other storms with fewer time samples, a total of 73 cases of S_1/S_2 ratios were obtained in 1963. The median ratio was 1.8 with the most frequent range from 1.6 to 2.0 which contained 25 percent of the 73 cases. Similarly, a median of 1.2 was found for L/L-1. The strong trend for a decrease in beta concentration at the start of a storm period is revealed by investigation of the frequency with which the decrease occurred. A decrease in excess of 10 percent occurred between the first and second samples in 80 percent of the cases, compared to an increase 8 percent of the time, and no change in 12 percent of the cases. An increase was found at the end of a storm period in 45 percent of the cases, compared to a decrease in 35 percent of the storms, and no change (10 percent or less) 20 percent of the time.

In another phase of this study, the ratios of S_1/A and L/A were grouped according to total storm rainfall, rainfall duration, and average rainfall rate. This was done to determine whether the relative magnitude of the initial sample and last sample might vary with the above storm rainfall factors. Results of this analysis are summarized in Table 9. This table indicates a trend for the S_1/A ratio to increase with increasing total storm rainfall, whereas the L/A ratio tends to remain constant with increasing volume of rainfall. No trend was found for the ratios to vary consistently with increasing rainfall duration or rainfall rate (Table 9).

TABLE 9

RELATION OP INITIAL AND PINAL BETA CONCENTRATION TO RAINFALL VOLUME, DURATION, AND RATE

Rainfall Volume (in.)	S_1/A	L/A
0.11 - 0.20	1.6	0.9
0.21 - 0.30	1.7	0.8
0.31 - 0.50	1.9	0.8
0.51 - 1.00	3.1	0.8
Rainfall Duration (hrs.)	**S_1/A**	**L/A**
0.1 - 1.0	1.9	0.8
1.1 - 2.0	1.8	0.9
2.1 - 3.0	2.2	0.7
3.1 - 6.0	3.2	0.8
over 6.0	1.4	lo5
Average Rate (in.)	**S_1/A**	**L/A**
0.11 - 0.25	2.3	1.0
0.26 - 0.50	1.7	0.8
0.51 - 1.00	2.1	0.7
1.01 - 1.50	1.7	0.9
over 1.50	2.1	0.8

The cause of the trend for the initial beta concentration to increase in heavier rainstorms cannot be completely isolated from analyses of the data. Heavier storm rainfalls may result from either storms of relative long duration or relatively heavy intensity with respect to the average. Both factors are present in the 1963 storms. Examination of the data for storms of 0.51-1.00 inch shows the median duration was 2.1 hours compared to a median of 1.3 hours for all 1963 storms, and a median rate of 0.62 inch/hour was found for these storms compared to 0.47 inch/hour for all storms. Further analysis of the storms with total rainfall amounts of 0.51-1.00 inch revealed a trend for the initial beta concentration to be greater with the longer duration storms in this group.

Evaporation from falling raindrops into the dry air at the forward edge of a storm is a factor which may influence the initial beta concentration in storms, but it does not appear that this influence should become greater as the areal extent and/or intensity of the storm system increases. A possible cause of the trend for the initial beta concentration to increase with increasing volume of storm rainfall may be a proportionately greater convergence of loose surface dirt and lower tropospheric particulates into the forward edge of the relatively larger storm systems associated with the heavier rainstorms. This would result in the capture and rainout of this dirt in raindrops and/or return of the entrained dirt to the surface in the storm downdrafts without capture by falling raindrops. Partial verification of this possibility can be made through analyses of the time samples of suspended and dissolved particulates in the beta samples from 1963 storms. These analyses are discussed in the next section. Other speculations as to causes of the trend discussed in the foregoing paragraphs could be presented, but since verification cannot be accomplished, little is to be gained by such discussions at this time.

Comparison of the data in Table 9 with synoptic types indicated that the trends observed in the beta concentration at the start and end of storm periods is not dependent to any large degree upon synoptic weather. For example, the three largest average ratios of the first to second storm sample occurred with a squall line on July 6, air mass thunderstorms on July 1, and a warm front on August 12. The largest average ratio at the end of a storm period was on June 10 with thunderstorms in an intense squall line, and the second largest ratio occurred with steady rain in advance of a warm front during the forenoon of July 13.

Rainfall Burst Relations

In a number of cases, storm periods consisted of several bursts, and in some of these cases rainwater samples were obtained at the start and end of two or more storm bursts. An investigation was made to determine whether an increase in beta concentration tended to occur at the start of new bursts in storms following the initial burst. Such information is valuable in determining the causes of the initial high beta concentration. The available data were divided into two groups. In the first, bursts were studied in which rainfall was continuous between bursts, the bursts being identified by decreasing rainfall rate followed by increasing rainfall rate later in the same storm period. The second group included all storms in which rain stopped for 0.1 to 1.0 hour between bursts.

The percentage change from the last sample in one burst to the initial sample in the next burst was calculated. With the first group, there were 33 cases obtained from storms with 2 to 4 bursts. In 16 cases (49%), an increase in beta concentration in excess of 10 percent was found, whereas 10 cases (30%) showed a decrease exceeding 10 percent, and 7 cases (21%) showed no change, that is, a change of 10 percent or less in either direction. When the second group was added to the first to include all eases with one hour or less between bursts, the number of cases increased to 52, and the percentage with increasing beta concentration from 49 to 54 percent. The percentage with decreasing beta concentration was 25 percent and the percentage of cases with no change remained at 21 percent.

The 16 cases of increasing beta concentration from burst to burst had a median value of 50 percent, whereas the 12 cases with 0.l to 1.0 hour between bursts had a median of 63 percent. Thus, the increase tended to be greater when rain stopped between bursts. Overall, there appeared to be a trend for beta concentration to increase with the beginning of a new burst, although the tendency was not exceptionally strong. The implication of these findings will be discussed later.

In completion of this phase of the study, the S_1/S_2 ratios in new bursts were calculated for comparison with the same ratio at the start of the storm period. When this was done, a median of 1.2 was found for both groups of storms, those in which new bursts occurred with continuous rainfall and those in which rainfall stopped for 0.1 to 1.0 hour between bursts. As shown earlier, the median value of this ratio at the beginning of 1963 storms was 1.8. Using only those storms incorporated in the burst analyses, the same initial ratio, 1.8, was obtained. Thus, a trend is indicated for the beta concentration to be relatively high at the start of new bursts, but the relative magnitude of this concentration with respect to later concentrations is not nearly as great as at the start of rainfall periods.

Further evaluation of the data for new bursts in storms showed the initial ratio (S_1/S_2) in new bursts had a decrease in excess of 10 percent between the first and second samples in 57 percent of the eases. An increase in excess of 10 percent was found in 34 percent of the cases, and no change (10% or less) in 9 percent of the storms. Comparable statistics for the first two samples at the beginning of a rainfall period (no previous rain) are 80, 8, and 12 percent, respectively, for decrease, increase and no change. These statistics indicate that the abnormally high initial concentration of beta activity occurs much more frequently at the forward edge of storm systems compared with occurrences at the start of new bursts within an existing storm system.

The comparison of S_1/S_2 ratios in the preceding paragraphs indicates the high initial values of beta concentration could be largely the result of evaporation of raindrops into dry air at the leading edge of storm systems. However, the tendencies for the beta concentration to increase from the end of one burst to the start of the next in saturated air and for the S_1/S_2 ratios to exceed 1.0 in new bursts suggests that other factors may be involved also. Convergence of surface and low level particulates into a storm and surface contamination of the rainwater collector by dry fallout have been mentioned. Although contamination of the collectors may not be a major cause of the initial high beta concentrations, it should be pointed out that the S_1/S_2 statistics would support the contamination hypothesis as well as the raindrop evaporation influence. That is, the collectors would be expected to have more contamination from dry fallout at the start of rain periods than would be found within storms. However, again, the contamination explanation does not account for the observations at the start of new bursts, particularly those for which there was no rain stoppage between bursts.

Another possible cause of the high initial beta concentration that has been suggested is that the raindrops at the forward edge of a storm system have had a longer residence time in the atmosphere, and, therefore, more time to become polluted with radioactive particulates. This hypothesis is based upon the assumption that the cloud droplets which grew to raindrops at the start of the storm were involved in the development stages of a convective storm, and that when the system was fully developed the residence time of the cloud and raindrops would decrease. This hypothesis has some support from the observed pattern of beta concentration between bursts; that is, assuming each burst represents a new convective cell, higher concentrations would be expected at the leading edge of new bursts than at the rear edge of the previous burst or subsequent samples in the new burst, providing the atmospheric supply of radioactive particulates to which the storm system is exposed remains constant. It is expected that further evidence of the veracity of the above hypothesis will be gained when analysis of the radar observation of convective cell activity over the network in 1963 storms is completed. This analysis should provide information on concentrations at the leading edges of both new and old convective cells.

S_1/S_2 Variability Within Storms

In search of further information to help evaluate the characteristics of the initially high beta concentration in storms and the causes of this anomaly in the distribution, analyses were made of the variability of S_1/S_2 ratios at the start of storm periods on the rainwater collection network. Storms were analysed in which four or more stations had time samples for the same storm period. Average values of the ratio and the average variability of the ratio are presented for 10 storms in Table 10. Network "ET" is the rainwater network used during June and July and encompasses approximately 3000 square miles, whereas Network "E" is the East Central Illinois raingage network of 400 square miles in which August operations were confined. Mean variability is equal to the average deviation from the network mean divided by the network mean and multiplied by 100. Maximum variability is the ratio of the highest to the lowest network value of S_1/S_2. It should be pointed out that the statistics in Table 10 are not based upon a uniform number of stations and so should be used only as general approximations.

Table 10 indicates large variability between stations in some storms, particularly on the larger network (ET) where the mean variability averaged 37 percent and maximum variability reached as high as 10.0. Both the mean and maximum variability decreased on the smaller network (E), with the mean variability averaging 21 percent for 6 storms and the maximum variability not exceeding 2.4. Both networks showed the same average ratio of 2.0 for S_1/S_2 for all storms combined. With network equivalent averages of S_1/S_2 and no outstanding differences in the network data that can be attributed to rainfall factors or synoptic storm types, it appears that the large differences in variability between networks is related to samples being drawn from a much larger area with the ET network. This, in turn, suggests that a wide range in S_1/S_2 is most likely to occur when a storm system is sampled over a relatively large portion of its area and/or a relatively long period of time, either of which would increase the probability of sampling individual elements of the system in various stages of development. If the preceding suppositions are correct regarding the statistics in Table 10, then the implication is that S_1/S_2 varies with the physical characteristics of the storm system, such as stage of development, age of convective cells, etc. Again, much more should be known about the veracity of these suppositions when detailed analyses of the radar data are completed.

Preliminary analysis of the pre-cold front squall line of June 10 provides some information on the variation of S_1/S_2 with ehanges in time and space. The pattern of ratios in this storm is shown in Figure 9. This squall line developed near the western edge of the network and moved ESE. At Station I, where a low ratio

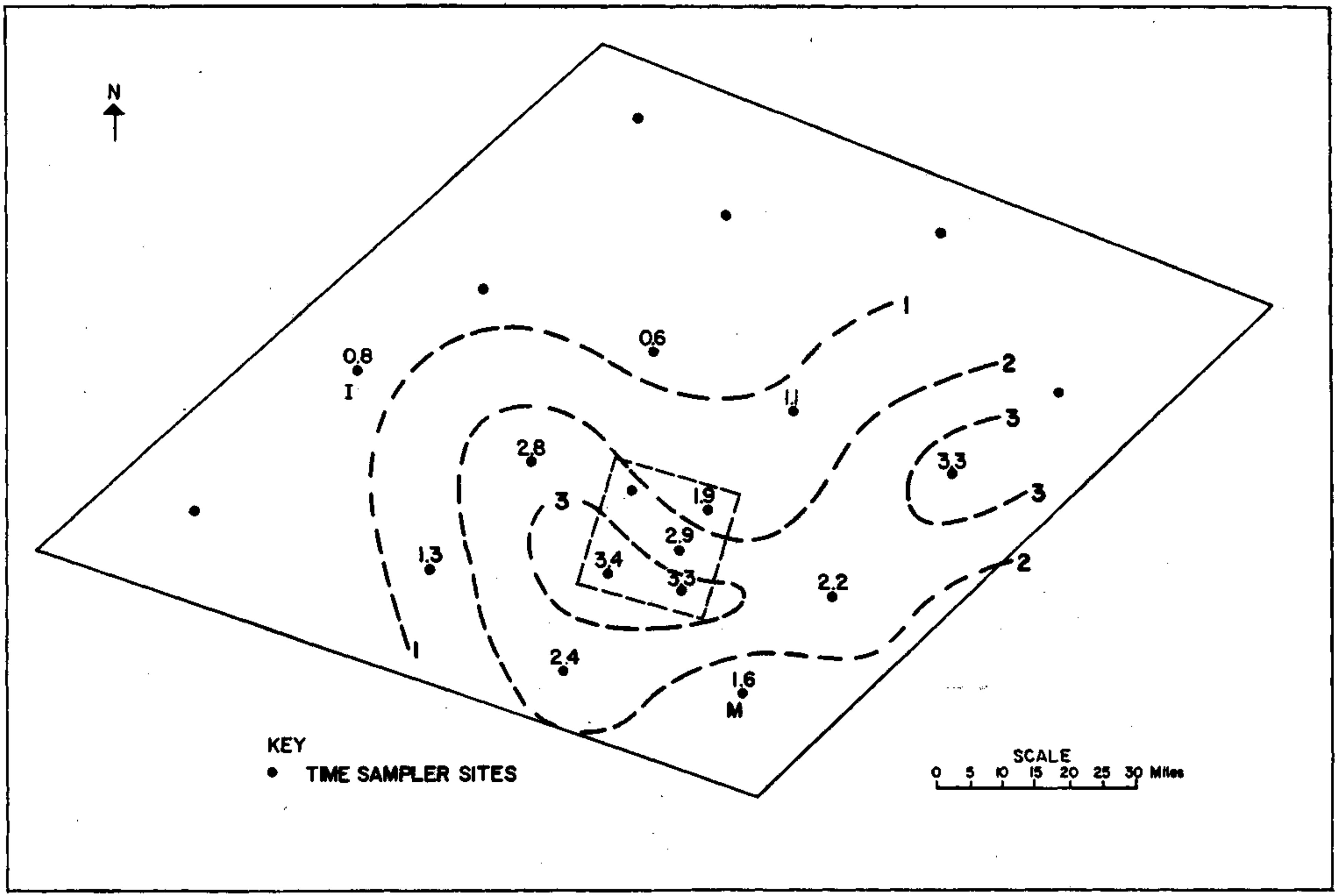


FIG. 9 S_1/S_2 IN STORM OF JUNE 10, 1963

TABLE 10

NETWORK S_1/S_2 STATISTICS

Storm Date	Average Ratio	Average Variability (%)	Maximum Variability (ratio)	Number of Stations	Network
6/10	2.1	37	5.7	13	ET
6/10	2.7	26	1.8	4	E
7/6	2.1	46	7.7	8	ET
7/33 (AM)	2o5	44	3.6	4	ET
7/13 (PM)	1.7	48	10.0	6	ET
7/20	1.7	11	1.3	4	ET
7/31	1.4	15	1.6	4	E
8/6	1.3	22	2.1	5	E
8/8	2.1	29	2.1	5	E
8/12	2.9	22	2.4	4	E
8/28	1.5	23	2.0	5	E

of 0.8 was obtained, the line was in the early stages of development. The pattern in Figure 9 shows a wide range of ratios and a region of relatively high ratios near the eastern edge of the network. Relatively large changes in ratio occurred within short distances. For example, values ranged from 1.9 to 3.4 within the East Central Illinois network of 400 square miles (dashed area). Analyses of radar data indicate that the zone of high ratios in the eastern part of the rainwater network was associated with a new line of storm echoes that developed immediately in advance of the original line. Correlation of Figure 9 with radar data from the CPS-9 and TPS-10 indicate the high ratios in the eastern part of the network occurred shortly after development of the new line, and Figure 9 indicates a decrease in the ratio later as the line reached Station M in the southeastern corner of the network. Radar-indicated cloud tops were in the range from 35,000 to 45,000 feet in the new line. The tropopause was near 35,000 feet. The cloud tops in the new line, however, were at approximately the same level as in the old line, so that vertical development does not appear to have been the cause of the zone of maximum ratios in the eastern part of the network. Development of this new line does indicate presence of a region of strong convergence, and entrainment

of the outflow from the old line may have been related to the high initial ratios in the new line.

Another factor investigated in conjunction with the S_1/S_2 ratios was the time elapsing between rainstorms in which appreciable rain occurred. This was done to determine if the ratios tended to be higher as the elapsed time between rains increased. If so, this would be indirect evidence of the importance of contamination of the initial rainwater sample by entrainment of loose surface dirt into the edge of a storm and/or storm washout of lower tropospheric dry fallout built up during the period of no rain. However, no strong correlation was indicated. For example, the highest average S1/S2 ratio (2.8) on the network occurred 4 - 6 days after heavy rains in central Illinois, whereas in several other cases ratios of 1.3 - 1.5 occurred with no appreciable rain for 7 - 10 days. However, other factors such as the wind velocity in the air mass in advance of a storm, and the intensity of convergence associated with the convective system would influence the entrainment of surface dirt into storms. Preliminary investigation of the particulate distribution in the rainwater samples used for beta analysis does suggest the presence of surface dirt in the initial beta samples. This investigation is described in the following section.

ANALYSES OF PARTICULATES IN 1963 STORMS

For each time sample in selected storms tabulations have been made of the amount of suspended and dissolved matter, the percentage of the total that was suspended, and the intensity of radioactivity in the particulate matter expressed as the number of micro microcuries per milligram (mmc/mg). Suspended material as used in this report is defined as the precipitate retained by filtration through a 0.45-micron Millipore filter. The dissolved material then refers to particulates in solution and particulates with diameters less than 0.45 micron.

These data are being used to evaluate the importance of the suspended and dissolved particulates in determination of the beta concentration in each rainwater sample and to determine whether significant changes occur within storms with respect to the proportions of suspended and dissolved material. The particulate radioactive intensity (mmc/mg) is used to determine intensity changes within storms that might be correlated with changes in the structure of the storm clouds, as portrayed by radar, and with changes in rainfall intensity at the surface.

The analyses of particulate matter are being used also in the investigation of the causes of the relatively high beta concentration frequently found in the rainwater samples at the start of a storm period. Although the particulate analyses have not been completed at this time, some interesting results have been obtained and are discussed briefly in the following paragraphs. Final results will be presented in a future report.

Analyses of 12 storm periods during 1963 have indicated a pronounced trend for the intensity of the radioactive rainout of particulates to be greater at the end of storm periods than at the start of rainfall. Results of this phase of the study are summarized in Table 11. In this table, ratios are shown for (1) the rainout intensity in the first rainwater sample (S_1)to the average rainout intensity for the entire storm period (A), and (2) the rainout intensity in the last sample (L) to the average storm intensity (A). Similar ratios are shown for the particulate weight, for the percentage of the total beta concentration resulting from suspended solids, and the percentage of the total weight of particulates accounted for by suspended material. The data in Table 11 are averages for the time sampler network, and include only storms in which four or more stations provided time samples. Also, only stations which collected a minimum of four time samples in a storm period were used.

Table 11 shows that in 10 of the 12 storm periods the rainout intensity ratio was greater at the end than at the start of the storm period. In one storm the two ratios were equal, and in the other storm the ratio was smaller at the end of the storm. The reversal in trend in the afternoon storm of July 13 occurred with a cold front passage following 6 to 8 hours of rainfall associated with the approach and passage of a warm front. It is stressed that the values in Table 11 are network averages, and departures from the average storm trend occurred at individual stations in some of the storms. For example, in the storm of June 10 three of the 12 stations used in the analysis had a rainout intensity greater at the start than at the end of the storm. Further investigation of possible causes of these reversals within storms will be made in conjunction with mesoscale case studies of storms now underway.

The pronounced trend for the rainout intensity to be greater at the end than at the start of storm periods indicates that more inert matter may be in the rainwater at the start of a storm, and, in turn, this indicates that the initial sample may be contaminated by the convergence of dirt into the forward edge of the storm system from surface or low-level sources. Sampler contamination would also contribute to the initially low rainout intensity. The foregoing suggestion gains further support by the ratios of particulate weight in Table 11. In all cases, the combined weight of suspended and

TABLE 11

COMPARISONS BETWEEN AVERAGE BETA CONCENTRATION AND AVERAGE RAINWATER PARTICULATE CONTENT IN 1963 STORM PERIODS

	Ratio of First and Last Sample to Storm Mean							
	Rainout Intensity (mmc/mg)		Particulate Weight (mg/1)		Percent Suspended Particulates		Percent Suspended Beta	
Storm Date	S_1/A	L/A	S_1/A	L/A	S_1/A	L/A	S_1/A	L/A
5/4	0.6	1.3	2.3	0.5	1.0	1.0	1.1	0.9
6/10	0.8	1.5	1.9	0.6	1.0	0.9	1.1	0.8
7/1	0.3	1.4	3.0	0.3	1.2	0.9	1.2	0.8
7/6	0.7	0.9	3.9	0.4	0.9	1.0	1.4	0.8
7/13 (AM)	0.8	1.4	4.6	0.4	0.9	0.9	1.4	0.7
7/13 (PM)	1.7	1.0	1.4	1.0	0.9	1.0	0.8	0.8
7/20	0.8	1.0	2.5	0.7	1.0	1.0	1.1	0.9
7/31	0.6	1.2	2.8	1.0	1.0	0.8	1.2	0.8
8/6	0.6	1.3	3.3	0.6	0.8	0.9	1.2	0.8
8/12	1.2	1.2	2.4	0.7	0.7	1.0	1.3	0.8
8/19	0.6	0.9	2.6	0.9	1.1	0.9	1.2	0.9
8/28	0.5	1.2	2.5	0.6	0.8	1.0	1.2	0.8
Average	0.8	1.2	2.8	0.6	0.9	0.9	1.2	0.8

dissolved material is greater at the start of the storms, and in most storms the ratio differences from the start to the end of the storm is pronounced.

The percentage of the total beta concentration produced by suspended solids shows the opposite trend from the rainout intensity. In 11 of the 12 storms, the ratio at the start of storms was greater than at the end of storms. Thus, the relative importance of the dissolved material increases near the end of storm periods.

Table 11 indicates little change, on the average, in the percentage of rainwater suspended particulates from the start to the end of storms. The decrease in the suspended percentage of the total beta concentration at the end of storms then results from a higher specific radioactivity of the dissolved material at the end compared to the beginning of storms, rather than a percentage increase in the dissolved material.

Summarizing, it appears that in most convective storms the greatest concentration of particulate matter is in the forward portion of the rain zone, and this suggests that the rainwater in this part of the storm may be contaminated by surface or low-level particulates brought in by strong convergence into the advancing storm. In turn, the contamination by surface and low-level particulates would tend to increase the total beta concentration in agreement with trends discussed in the last section. However, the radioactivity of the surface and low-level particulates would be relatively low compared to that of material brought down from high-altitude storage of fission products, since they would include much non-radioactive material as well as previous radioactive dry fallout or rainout material. This should result in a relatively low beta concentration per unit weight of particulates at the start of storms. Continuing the preceding line of thought, the surface contamination would be expected to decrease in intensity as a storm is penetrated farther. This should result in a decrease in the total amount of particulate matter per unit volume of rainwater, but the rainout intensity should increase. As pointed out earlier, a general tendency in this direction was found in the 12 storms.

The foregoing discussion indicates that the relatively high beta concentrations observed at the beginning of a majority of the 1963 rainstorms was partially due to contamination of the rainwater by surface or low-level particulates. However, evidence was presented in the previous section to show that the initial concentrations tend to be higher than the average concentration in storms where the surface contamination factor is negligible. Thus, surface contamination does not appear to be the sole cause of the high initial beta concentrations frequently observed. Evaporation from falling raindrops at the forward edge of storms is another contributing factor, but should not be an important factor in most warm-season convective storms in Illinois that usually occur in moist tropical air.

1962 STRONTIUM ANALYSES

A total of 92 total storm samples from 12 storms were analysed for Sr-89 and Sr-90 in 1962 (Walton and others, 1963). of these storms, five or more samples were obtained in the Boneyard, Kaskaskia,or East Central Illinois networks. These networks are described in the first progress report under this contract (Huff, 1963). Network averages for the above storms are listed in Table 12, All except one storm, October 1-2, produced convective rainfall in conjunction with showers and thunderstorms. All storms were classified as moderate to heavy with respect to rainfall. Table 12 shows that a relatively wide range of concentrations and depositions were sampled, especially with Sr-89. In Table 12, concentration is expressed in micro microcuries per liter (mmc/l) and deposition in micro microcuries per square meter (mmc/sq.m),

TABLE 12

NETWORK AVERAGES OP STRONTIUM CONCENTRATION, STRONTIUM DEPOSITION, AND STORM RAINFALL IN 1962

Storm Date	Network	Number of Samples	Average Concentratl on (mmc/l)		Average Deposition (mmc/sq.m)		Storm Rainfall (in.)
			Sr-89	Sr-90	Sr-89	Sr-90	
7/2-3	E*	6	33	4.5	1548	212	1.77
7/2-3	B	5	38	5.5	3659	531	3.84
7/2-3	K	5	33	5.5	3006	497	3.59
7/11	K	5	241	6.0	4681	115	0.74
7/13	E	10	130	6.3	6030	286	1.61
7/14-15	K	5	283	6.9	2831	344	1.95
7/22	E	9	84	13.3	1631	259	0.82
8/5	K	5	47	4.1	1828	159	1.52
8/24	E	9	29	4.1	598	81	0.80
10/1-2	E	10	216	12.3	2022	113	0.33

*E - East Central Illinois, B - Boneyard, K - Kaskaskia

Spatial Variability of Strontium

An investigation was made of the spatial relative variability of strontium, and comparisons were made with similar calculations for gross beta activity from 1962 data. The purpose of this investigation was to obtain quantitative data on the probable variability of radioactivity on a mesoscale in convective storms and to determine the relationship between the relative variability of radioactivity and storm rainfall. The relative variability was calculated by the simple method of Conrad (1950), in which it is defined as:

$$V = 100(AD/M)$$

where V is the relative variability in percent, M is the mean of the sample, and AD is the average deviation from the mean.

The relative variability of strontium concentration, strontium deposition, and storm rainfall are summarized in Table 13 for the storms listed in Table 12. The Boneyard network encompasses an area of 10 square miles, the Kaskaskia network 12 square miles, and the East Central Illinois network 400 square miles. The rainfall relative variability in Table 13 was based upon observations at the same points at which the strontium samples were collected. Concentration refers to the quantity of radioactive material per unit volume of rainwater, whereas deposition is the quantity of radioactive material deposited per unit area.

Table 13 shows that, on the average, the relative variability for both the concentration and deposition of Sr-89 and Sr-90 was somewhat higher than the variability of storm rainfall. The average variabilities of Sr-89 and Sr-90 were approximately equal on the Kaskaskia and Boneyard networks. Table 14 shows the average relative variability of beta concentration and deposition, based on 15 storms in 1962 from the Kaskaskia and Boneyard networks discussed in an earlier report (Huff, 1963). The data from these networks were combined since they represent nearly equal sampling areas. Comparison of Tables 13 and 14 indicates that, in general, the relative variability of gross beta is somewhat greater than that of either strontium-89 or strontium-90. Beta concentration had a 15-storm average of 25 percent compared with the 5-storm average of 15 percent for strontium, and beta deposition averaged 25 percent compared with 20 percent for strontium. Of course, these statistics are based upon a relatively small sample, especially the strontium data, and they may be altered as more storms are analysed. However, the differences are in the expected direction, since the beta variability reflects the combined variability of a large number of fission products. Since total storm rainfall has equal weight with concentration in calculation of the deposition in each case, smaller differences between the relative variability of strontium and beta deposition would be expected, as found in the 1962 storms.

The relative variability in the five 1962 storms on the East Central Illinois network of 400 square miles (Table 13) showed the same general trend as observed on the two small networks. The storm of October 1-2 consisted of mostly stable rainfall with a few convective cells interspersed in the stable cloud layers. Table 13 indicates that the variability in this storm did not depart greatly from that observed in the convective storms, and

TABLE 13

RELATIVE VARIABILITY OP STRONTIUM-89, STRONTIUM-90, AND STORM RAINFALL ON KASKASKIA, BONEYARD, AND EAST CENTRAL ILLINOIS NETWORKS IN 1962

Storm Date	Network	Sr-89 Conc.*	Sr-89 Dep.*	Sr-90 Conc.*	Sr-90 Dep.*	Storm Rainfall	Mean Rainfall Depth (in.)
		Relative Variability (%)					
7/2-3	K**	8	12	18	15	17	3.59
7/2-3	B	14	14	13	14	6	3.84
7/11	K	26	33	14	25	12	0.74
7/14-15	K	11	23	12	26	13	1.95
8/5	K	14	19	20	21	10	1.52
Average	K+B	15	20	15	20	12	2.33
Median	K+B	14	19	14	21	12	1.95
7/2-3	E	16	14	20	17	11	1.77
7/13	E	20	16	25	23	13	1.61
7/22	E	23	31	14	29	23	0.82
8/24	E	23	29	24	20	21	0.80
10/1-2	E	20	28	12	13	12	0.33
Average	E	20	28	19	20	16	1.07
Median	E	20	28	20	20	13	0.82

* = Conc. - Concentration, Dep. - Deposition

** = K - Kaskaskia, B - Boneyard, E - East Central Illinois

TABLE 14

AVERAGE RELATIVE VARIABILITY OP GROSS BETA IN 1962
STORMS ON KASKASKIA AND BONEYARD NETWORKS

	Average Relative Variability (%)	Number of Storms
Beta Concentration	25	15
Beta Deposition	25	15
Storm Rainfall	14	15

indicates that the relative variability can be quite large in these storms. Combining all storms, the relative variability of the total storm rainfall was somewhat less than that of strontium concentration and deposition on the 400 square mile network, and as with the other networks, this trend did not apply to all storms but to the majority. In general, the relative variability of strontium and storm rainfall was somewhat greater on the larger network (East Central Illinois) as expected.

In summary, the above findings support those presented in the first progress report that were based upon gross beta analyses and incomplete analyses of strontium data for 1962. On the average, the relative variability of both individual isotopes and gross beta exceed the rainfall relative variability. Beta shows greater variability than the individual isotopes, and the variability of all factors increases with area, as expected. The greater spatial variability of the radioactive rainout in comparison with storm rainfall indicates that rainfall exerts only partial control on the radioactive rainout pattern. The surface rainout is undoubtedly related to the drop size distribution of cloud droplets, and this distribution should be highly variable in convective storms, such as analysed in this study. A much larger sample is needed to define the variability relationships accurately; data collected in 1963 that is now under analysis should aid considerably in defining the relationships.

Age of Debris in 1962 Storms

The age of debris in 1962 storms, as indicated by ratios of Sr-89 and Sr-90, is summarized in Table 15 for eight storms. This table shows the average age on the sampling networks, the range of age values on each network, the relative variability of the debris age in each storm, the maximum variability as measured by the ratio of the maximum to minimum value on the network, and average network rainfall. The debris analysis was made to determine whether a relationship exists between rainfall and age of debris in convective storms. Deep vertical development of convective storms favors the production of heavy rainfall. If the more deeply developed storms substantially penetrate the stratospheric reservoir of radioactive debris, then a relationship might exist between debris age and rainfall magnitude.

TABLE 15

AGE OP DEBRIS IN 1962 STORMS

Storm Date	Network	Number of Samples	Age (Days) Average	Age (Days) Range
7/2-3	E	6	227	221-230
7/2-3	B	5	228	205-254
7/2-3	K	5	240	221-254
7/11	K	5	108	82-122
7/11	E	3	130	108-142
7/13	E	10	154	129-176
7/14-15	K	5	104	91-113
7/22	E	9	237	205-270
7/22	B	4	282	212-419
8/5	K	5	193	171-230
8/24	E	9	229	192-291
10/1-2	E	10	166	140-186

Storm Date	Network	Number of Samples	Relative Variability (percent)	Maximum Variability Ratio	Rainfall (in.)
7/2-3	E	6	11	1.04	1.77
7/2-3	B	5	16	1.24	3*84
7/2-3	K	5	7	1.15	3.59
7/11	K	5	10	1.49	0.74
7/11	E	3	--	----	----
7/13	E	10	9	2.26	1.61
7/14-15	K	5	5	1.24	1.95
7/22	E	9	14	1.32	0.82
7/22	B	4	--	1.98	----
8/5	K	5	17	1.35	1.52
8/24	E	9	19	1.52	0.80
10/1-2	E	10	10	1.33	0.33

The average relative variability for the Kaskaskia and Boneyard networks, based upon five storms, was 11 percent compared with 13 percent for five storms on the East Central Illinois network. Comparing these variabilities with the data in Table 13, it is seen that the age variability is nearly equal to the rainfall variability in these same storms, and considerably less than the variability in the concentration and deposition of Sr-89 and Sr-90. The maximum variability shows values ranging from 1.04 to 2.26 on the East Central Illinois network, and from 1.15 to 1.98 on the small networks.

Table 15 indicates that no strong relationship exists between the average age of the radioactive debris and rainstorm magnitude, as measured by the average network rainfall. A similar conclusion is reached regarding the debris variability and the network mean rainfall. Graphical plots of age against storm rainfall at individual stations in the various storms led to a similar conclusion, that is, the point-to-point correlation between storm rainfall and debris age is weak. Also, comparisons of the areal patterns of debris age and storm rainfall were made. Results were inconclusive; in some storms highs and lows in the patterns were in close proximity, and in other storms the association was poor. In general, it appears that a strong correlation does not exist between the patterns of rainfall and debris age.

Correlation Between Strontium Rainout and Rainfall Factors

Correlation coefficients were calculated between the concentration and deposition of Sr-89 and Sr-90 and three rainfall factors, rainfall volume, rainfall duration, and average rainfall rate. These correlations were made for five storms in 1962 in which nine or more storm samples were obtained on the networks. Results were similar to those obtained with the 1962 beta correlations discussed in the first progress report. In general, relatively poor correlation was found between the strontium deposition and concentration and the three rainfall factors. The highest correlations were found with rainfall volume and the correlation tended to be somewhat better with strontium deposition than with concentration, as shown in Table 16. Thus, it appears that rainfall at a given point cannot be used as an accurate and reliable predictor of storm radioactive rainout at the same point. This conclusion is given further support by correlation coefficients obtained between beta concentration and the three rainfall factors in six storms in 1962 and 18 storms in 1963. Nine of the 18 storms used in the 1963 correlation were on the East Central Illinois network, and the other nine storms were on the larger time sampler network (Fig. 1). Again, rainfall volume correlated best in these 24. storms, and a median value of -0.36 was obtained for the 24 correlation coefficients. Coefficients ranged from 0.58 through zero to -0.82. Areal relationships between radioactive rainout and rainfall will be discussed later.

TABLE 16

CORRELATION COEFFICIENTS BETWEEN STRONTIUM CONCENTRATION, DEPOSITION, AND RAINFALL VOLUME

Storm Date	Sr-89 Conc.	Sr-89 Dep.	Sr-90 Conc.	Sr-90 Dep.
	Correlation Coefficient with Rainfall Volume			
7/2-3	0.02	0.82	0.28	0.87
7/13	-0.49	0.34	-0.67	-0.22
7/22	-0.41	0.58	-0.23	0.71
8/24	0.02	0.31	-0.53	0.12
10/1-2	0.40	0.65	-0.09	0.11

Next, comparisons were made between the areal patterns of strontium rainout and storm rainfall in 1962 storms. Nine storms were available for this purpose. It is quite possible for point-to-point correlations to be poor, whereas areal patterns may show considerable similarity. For example, high and low regions in the patterns would be displaced from each other if the greatest concentration of radioactivity tended to occur near the edge of convective cells, instead of near the center.

When the pattern comparisons were made, results were inconclusive although the strontium patterns frequently showed a definite relationship with respect to highs and lows. Thus, the pattern of Sr-89 concentration showed regions of relatively high concentration in close proximity to similar high regions in the storm rainfall pattern in three storms and fair association in another storm. However, an inverse relationship was also noted in four other storms, that is, highs in the Sr-89 concentration pattern corresponded to lows in the network rainfall pattern and vice versa. Excellent correspondence was found between the patterns of Sr-90 concentration and storm rainfall in seven of the nine storms, but again both direct and inverse relationships were indicated. With Sr-90 concentration, direct relations were indicated in five storms, and inverse relations in two storms. It appears likely that the inverse relation occurs when the entire storm mass is subjected to an approximately uniform distribution of radioactivity during its life, so that in the heavier rainfall regions the particulate concentration is relatively light, whereas in the light rainfall regions the reverse occurs. When the concentration of radioactive debris peaks in the vicinity of a heavy rainfall region, it is likely that the convective system has developed to a considerably higher level in that region and has penetrated a stratospheric layer of relatively heavy radioactivity. As pointed out in a preceding section, this condition is most likely to occur with the initial stratospheric penetration in the early stages of development of a convective system. Regardless of the cause, the dilution effect in the heavier rainfall areas is more than offset by access to a heavier concentration.

The patterns of deposition of both Sr-89 and Sr-90 indicated a close correspondence in patterns in most of the nine storms. In eight of the nine storms, highs and lows in the deposition patterns were found to occur quite close to similar highs and lows in the storm rainfall pattern, and in each case the relationship was direct.

Prom the foregoing discussion of the 1962 strontium patterns, it is concluded that, with allowance for reasonable spatial displacement, the areal patterns of strontium deposition and storm rainfall are generally similar. The strontium concentration pattern is dictated more by developments in the convective cloud system, and does not show a consistent pattern relationship with storm rainfall, although there is a tendency for an inverse relationship between patterns. In the cases studied to date, the spatial displacement of the radioactivity centers from the storm rainfall centers was not consistent with respect to direction or distance. It is probably related to both the direction and speed of movement of the convective cells Involved in the rainfall. This displacement is a subject for future study.

The above conclusions are based upon a very small sample and should be verified with more data. When completed, the 1963 data should do much to establish the existence and reliability of the pattern relationships.

Strontium Concentration and Debris Age Vs. Meteorological Parameters

Table 17 shows comparisons between strontium concentration, debris age, tropopause height, average and maximum cloud tops in the network region as indicated by radar, and the approximate distance of the jet stream from the sampling networks. The concentrations and ages for the eight storms are averages for all observations on all networks combined, and represent a mean for east-central Illinois.

Examination of the data in Table 17 does not indicate a strong correlation between strontium concentration and debris age with any particular meteorological parameter listed in the table. These data do not support the findings of Kruger and Hosier (1963) that the concentration of radioactivity increases with proximity to the jet stream. However, the Illinois sample is small and more data may alter the indications of Table 17.

TABLE 17

STRONTIUM CONCENTRATION AND DEBRIS AGE VS. METEOROLOGICAL PARAMETERS IN 1962

Storm Date	Concentration Sr-89	Sr-90	Debris Age (days)	Tropopause (ft)
7/2-3	35	5.2	232	48,000
7/11	243	7.1	116	47,000
7/13	130	6.3	154	47,000
7/14-15	283	6.9	104	50,000
7/22	77	12.6	251	40,000
8/5	47	4.1	193	47,000
8/24	29	4.1	229	14.8,000
10/1-2	216	12.3	166	35,000

Storm Date	Average Cloud Tops (ft)	Maximum Cloud Tops (ft)	Jet Stream Distance (mi)
7/2-3	30,000	45,000	275
7/11	35,000	45,000	275
7/13	35,000	55,000	275
7/14-15	27,000	47,000	400
7/22	35,ooo	53,000	125
8/5	40,000	50,000	0
8/24	30,000	38,000	300
10/1-2	20,000	30,000	125

1963 STRONTIUM ANALYSES

As mentioned earlier in this report, radiochemical analyses of only 85 of the 400 strontium samples had been completed when preparation of this report was started. These 85 samples were obtained in the storms of April 17, April 19, and April 22, when Project Springfield was in operation. The samples were taken primarily for use in the analyses of the Springfield data. No RHI radar data are available for these days, since maintenance started on the TPS-10 in early spring had not been completed at that time. However, CPS-9 data are available, and include some RHI data obtained with the antenna tilt program. No detailed analyses of meteorological data on these dates have been attempted, since it is understood that Professor Danielson is undertaking a detailed study of the data.

The April radiochemical analyses have been used for comparison with beta analyses on the same dates and have provided some interesting results. In general, the same trends were observed with the individual radionuclides as with the beta data. The similarity in trends is illustrated in Figure 10 which shows a graphical plot of strontium-90 concentration against gross beta concentration for total storm samples on the three storm dates. Figure 11 shows a plot of time samples of strontium-90 and gross beta at three stations on April 22. Only light scattered rainfall in the form of thunderstorms occurred on the network, so that few time samples were obtained. Figure 11 indicates a relatively strong relationship between gross beta and strontium concentration in the few samples on April 22.

The subcontractor furnished rather complete analyses of Ce-144 for the samples on April 22, in addition to the Sr-89 and Sr-90 analyses. The time distribution pattern of these three radionuclides are shown at Station N in Figure 12, along with the gross beta distribution. The patterns are strikingly similar.

The data for the three April storms are not sufficient to reach reliable conclusions. However, if the observed trends continue to occur in future analyses, it would appear that beta data provide a relatively inexpensive source of data to conduct studies on the atmospheric processes involved in the rainout of radioactivity. With the nuclear test ban treaty in force, the beta decay problem is less acute also, and makes this data more useful in meteorological analyses.

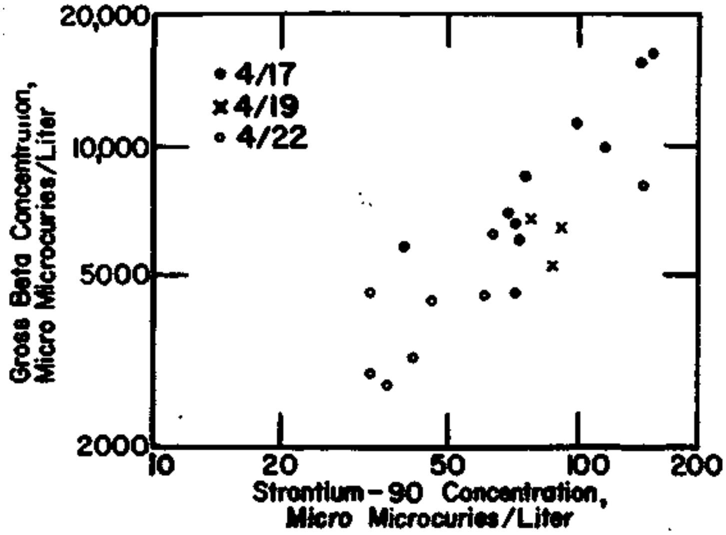
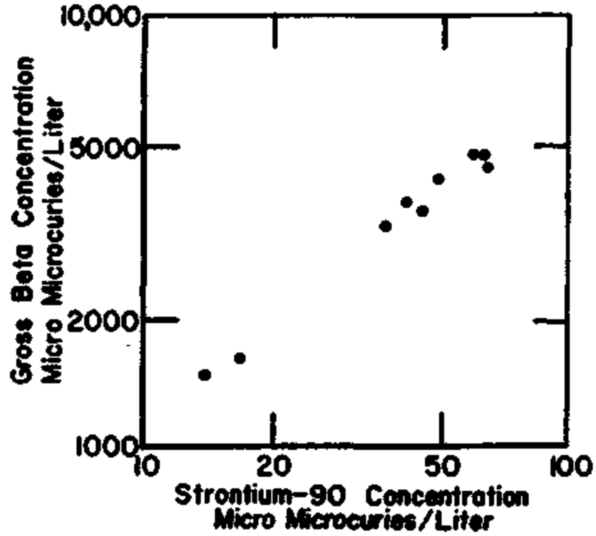


FIG.10 COMPARISON OF TOTAL STORM CONCENTRATION IN THREE APRIL STORMS



FI6.II COMPARISON OF TIME SAMPLE CONCENTRATION ON APRIL 22, 1963

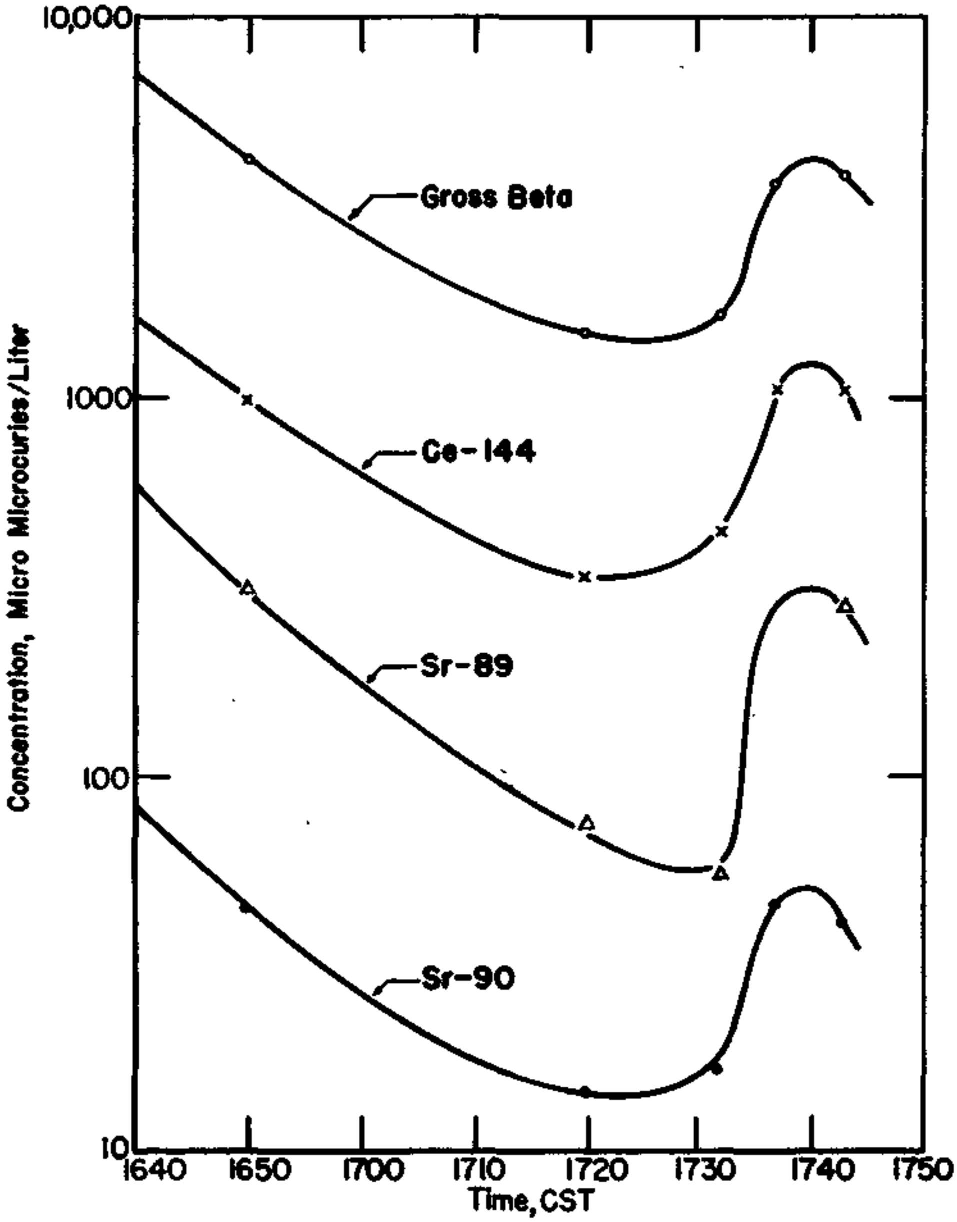


FIG.12 TIME DISTRIBUTION PATTERNS OF RADIOACTIVITY CONCENTRATIONS AT STATION N ON APRIL 22, 1963

RELATIONS BETWEEN BETA ACTIVITY AND RAINFALL IN 1963

Data from the time sampler network of approximately 6000 square miles and the East Central Illinois network of 400 square miles (Fig. 1) were used to investigate the relationships between gross beta concentration and deposition and storm rainfall factors. This investigation was a continuance and expansion of the analyses performed on 1962 data.

Point Relations

Correlation coefficients were calculated for total storm periods between concentration and deposition of gross beta and storm rainfall volume, rainfall duration, and average rainfall rate. This analysis was performed for nine storms on each network. The results are summarized in Table 18 in which median values of the correlation coefficient are given for the 9-storm sample in each network.

TABLE 18

CORRELATION COEFFICIENTS BETWEEN GROSS BETA AND RAINFALL FACTORS

	Correlation with Beta Concentration		
Network	Rainfall Volume	Rainfall Duration	Rainfall Rate
East Central Illinois	-0.63	-0.40	-0.24
Time Sampler	-0.39	-0.24	-0.29
	Correlation with Beta Deposition		
	Rainfall Volume	Rainfall Duration	Rainfall Rate
East Central Illinois	0.64	0.41	0.26
Time Sampler	0.70	0.31	0.48

The summarized results of the correlation analyses in Table 18 indicate a general trend for gross beta concentration to decrease with increasing rainfall volume, duration, and rate. Gross beta deposition shows a general trend to increase with the three rainfall factors. The strongest correlation is found with storm rainfall volume, as expected, since it incorporates the influences of both duration and rate.

The correlation coefficients are not outstanding in any case. For example, the highest median coefficient of 0.70 between rainfall volume and deposition on the time sampler network indicates that only about 49 percent of the variance in beta deposition is explained by the variation in storm rainfall amounts. Furthermore, in most of the various categories presented in Table 18 the correlation coefficient had a wide range from positive to negative values among the nine storms. For example, the correlation coefficient between beta concentration and rainfall volume varied from 0.58 through zero to -0.77 on the East Central Illinois network. However, the deposition trend was much more stable since only one negative coefficient resulted from the correlations between rainfall volume and beta deposition on the East Central Illinois network and all coefficients were positive on the larger time sampler network. With duration and rate, considerable fluctuation from negative to positive coefficients occurred with both concentration and deposition.

Figure 13 shows typical graphical plots of total storm rainfall amount against mean beta concentration in eight storms. All available data from the rainwater sampling network were used in the plots of Figure 13; however, only the East Central Illinois network of 400 square miles was in operation during the August storms. The eight storms were selected to illustrate typical correlations between radioactive rainout and rainfall volume at a group of points in a relatively small area in the same convective storm. In some storms, such as those of June 10, July 1, and August 28, there was a pronounced trend for the beta concentration to vary inversely with rainfall amount. Correlation coefficients of -0.82, -0.76, and -0.77, respectively, were obtained in these three storms. In other storms shown in Figure 13, however, the inverse trend was relatively weak, and in the storm of August 6, the trend was reversed to produce a correlation coefficient of 0.58. Several investigators, employing storm-to-storm data at a single point, have noted an inverse correlation between specific radioactivity and rainfall amount. The results of the Illinois study, employing multiple sampling points within the same storm, lead to the conclusion that an inverse correlation usually prevails from point-to-point in convective storms, but the correlation is often weak, and occasionally, the correlation is positive rather than negative.

The correlation coefficients between gross beta and storm rainfall volume in 1963 storms were somewhat better than found between strontium and rainfall in five 1962 storms, discussed in a previous section. This difference may be largely the result of sampling vagaries, and the 1963 strontium analyses should clarify the situation. The general conclusion at this stage in the study

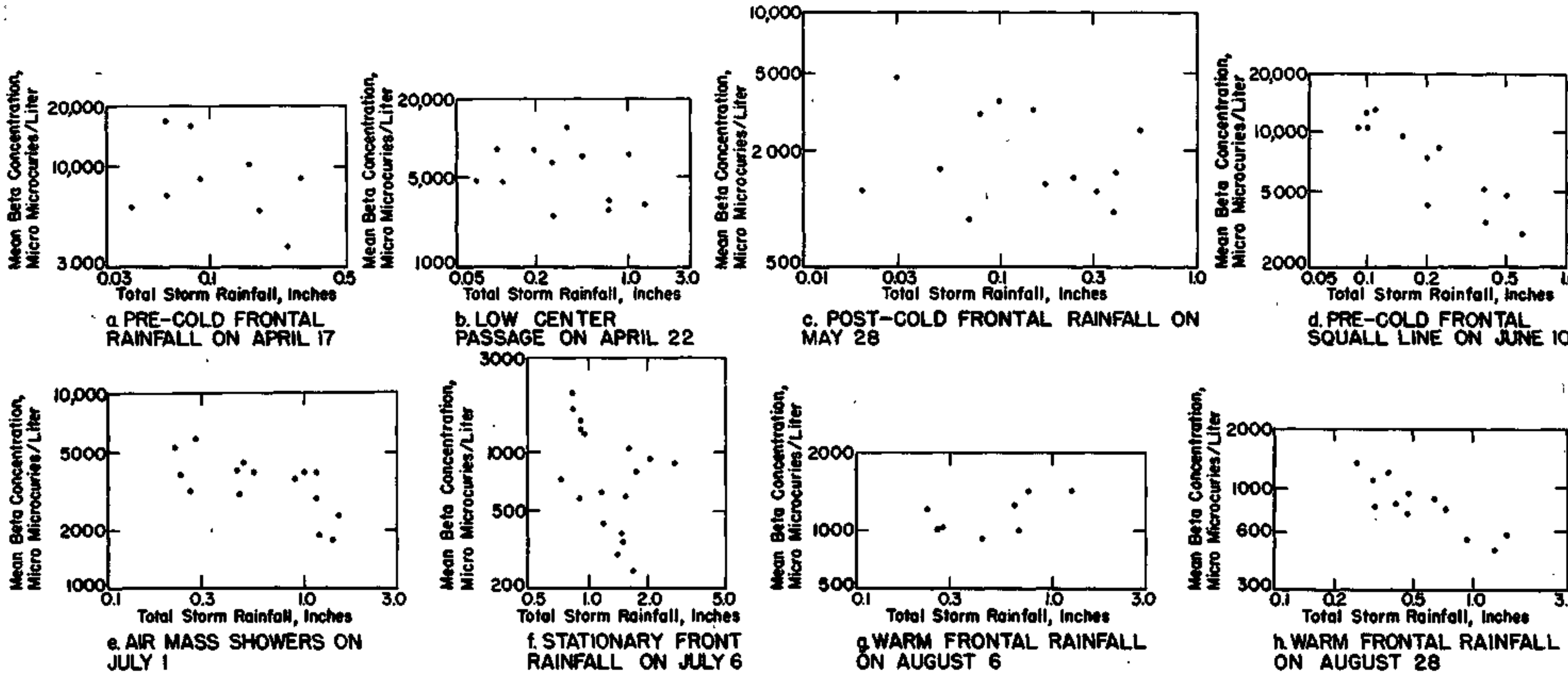


FIG.13 RELATION BETWEEN GROSS BETA CONCENTRATION AND STORM RAINFALL IN SELECTED 1963 STORMS

must be that neither the concentration nor the deposition of radioactivity can be predicted consistently or accurately at a given point from the rainfall characteristics at that point.

An effort was made to determine whether the point-to-point correlation between radioactivity and rainfall would improve if time sample data instead of total storm data were used. The rainwater time samples in most 1963 storms contained 0.04 to 0.06 inch, and up to 12 samples were obtained at stations in the time sampler network.

For each of 20 storms in which a large number of time samples were obtained within the network, graphical plots were made in which gross beta concentration was related to rainfall rate. The scatter of points in most storms was relatively great, and indicated a low degree of correlation. For example, in the storm of June 10, a total of 60 time samples was obtained from 12 stations, and the correlation coefficient was -0.35 between beta concentration and rainfall rate for the 60 samples. Since the graphical plots indicated this storm provided one of the better relationships among the 20 storms investigated, no further mathematical calculations were made. In the 20 storms, the trend found most frequently was for the beta concentration to decrease with rainfall rate, but the opposite tendency occurred in several storms, as would be expected from the findings presented in the section on beta distribution characteristics. Also, strong mathematical correlations should not be expected in view of findings (1) that the beta distribution type may vary among stations within a small area in the same storm, and (2) that a lag exists between the peaks and valleys in the beta and rainfall rate distribution patterns at a given point.

Areal Pattern Relations

Following the procedure used in the first progress report and discussed previously in conjunction with the 1962 strontium analyses in this report, a comparison was made of the network patterns of beta concentration and deposition and total storm rainfall in 1963 storms. The nine storms analysed on the East Central Illinois network were used for this purpose.

These areal comparisons revealed a relatively strong association between the areal patterns of beta deposition and storm rainfall in seven of the nine storms, with respect to the location of highs and lows in the patterns. Allowance was made for displacement of the high and low centers from each other, since displacement might occur with such factors as storm movement and raindrop fall velocity, but in no case did the spatial displacement exceed six miles, when the association was rated strong. In all cases, high beta deposition tended to be associated with high rainfall volume, and vice versa. The areal patterns of beta concentration and storm rainfall did not compare as favorably as the patterns of deposition and rainfall. The association of patterns was relatively strong in six of the nine storms, but, similar to the findings with the 1962 strontium data, the high and low association was not consistent. High beta concentration occurred in low rainfall regions in five of the six cases, whereas, in the other ease, the association was strong but high beta concentration was ' associated with high rainfall values. As a result of the investigation on beta distribution characteristics discussed earlier, this reversal in trend in some storms is to be expected, but, of course, limits the usefulness of surface rainfall observations in evaluating storm rainout of radioactivity.

An example of pattern associations is illustrated in Figure 14 for the storm of July 1 on the East Central Illinois network. Relatively high beta concentrations in the northern and southeastern parts of the network correspond with relatively light rainfall in these regions. A region of relatively light beta concentration extends from the eastern to the southern part of the network, but is displaced about three miles east of the corresponding rainfall high in the south central part of the network. Similarly, generally close association is indicated between regions of highs and lows in the beta deposition and rainfall patterns, although the high centers are displaced from each other by several miles.

The results of the 1963 beta pattern study compare favorably with those reported in nine storms in 1962 on the small Kaskaskia and Boneyard networks, in which six of the nine storms showed a relatively strong association between beta and storm rainfall patterns (Huff. 1963). Also, results compare favorably with those obtained with strontium patterns, discussed in a previous section of this report.

Network Relative Variability

Calculations were made of the network relative variability of gross beta and storm rainfall on the East Central Illinois network of 400 square miles in 1963 storms. Nine storms in which total storm rainwater samples were obtained at nine or more stations on the network were used in the calculations. Relative variability was determined by the method of Conrad (1950) discussed earlier.

Results are summarized in Table 19 in which median values for the 9-storm sample are shown for beta concentration, beta deposition, and storm rainfall volume. Table 19 also shows data abstracted from the first progress report for 15 storms on the small Boneyard and Kaskaskia networks (10 and 12 square miles).

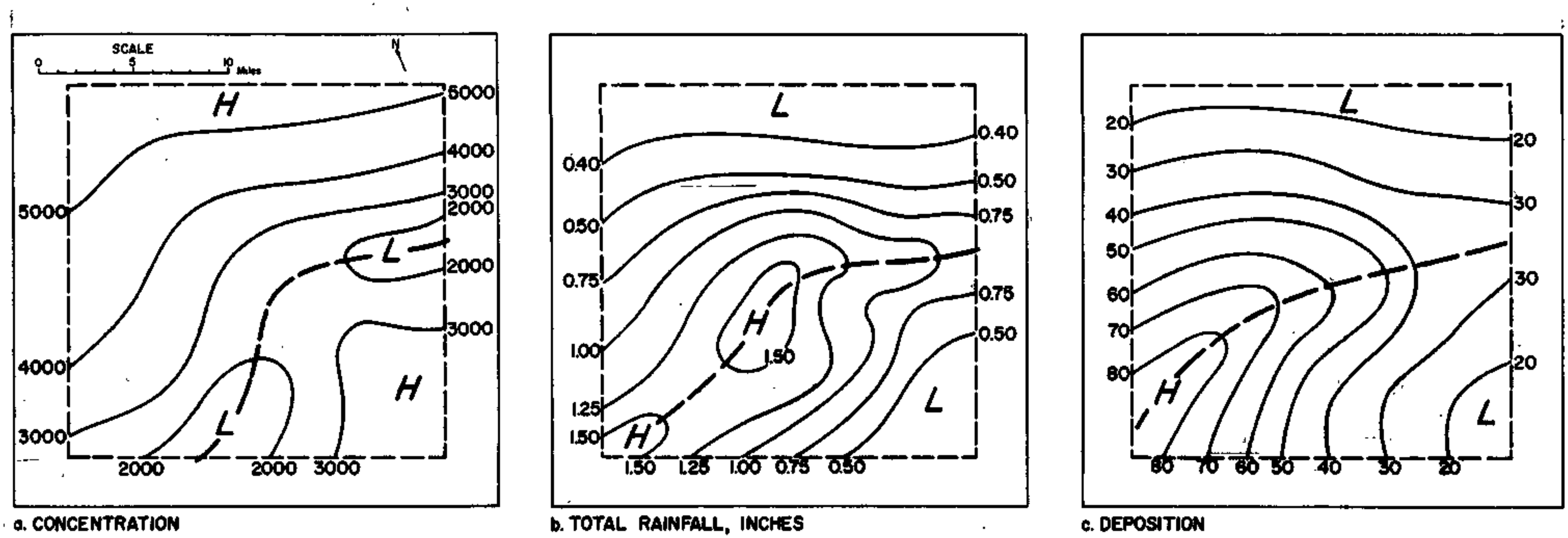


FIG.14 AREAL PATTERNS OF BETA CONCENTRATION, BETA DEPOSITION, AND STORM RAINFALL IN EAST CENTRAL ILLINOIS NETWORK ON JULY 1, 1963

Individual values of relative variability in 1963 storms ranged from 16 to 47 percent for beta concentration,. 16 to 63 percent for beta deposition, and 11 to 54 percent for storm rainfall. Both sets of data in Table 19 indicate a trend for the beta variability to exceed the storm rainfall variability, and stress the magnitude of the spatial variability of radioactive rainout that may occur in convective storms.

TABLE 19

RELATIVE VARIABILITY OP BETA ACTIVITY AND STORM RAINFALL

Network	Beta Conc.	Beta Dep.	Storm Rainfall	Number of Storms
East Central Illinois	26	33	24	9
Kaskaskia - Boneyard	23	20	12	15

Point Sample Representativeness

As pointed out in the first progress report, knowledge of the accuracy with which a point radioactivity measurement represents the mean storm fallout for areas of various sizes has application in investigations aimed toward defining the atmospheric processes that control radioactive rainout and is useful in the design of sampling networks for health hazard monitoring. Following the procedure used with the Kaskaskia and Boneyard data in 19o2 storms, the areal representativeness of a central sampling point in the measurement of average areal radioactive rainout was calculated in nine 1963 storms on the East Central Illinois network. In this calculation, the deviation of the central gage value from the areal mean, as determined from the average of all network samples, was expressed as a percentage of the areal mean. It was assumed that the network average represented accurate estimates of the true area average, and the central gage differences were considered sampling errors.

Results of these calculations for the nine storms are summarized in Table 20. Sampling errors are shown for beta concentration, beta deposition, and storm rainfall. Storm rainfall was included as a guide in evaluating the magnitude of the beta sampling error, since much more Information is available on the magnitude of rainfall sampling errors with respect to storm volume, storm type, size of sampling area, etc. (Huff and Neill, 1957).

Table 20 shows an average sampling error of 30 percent for the central sampling point measurement of beta concentration in the 9-storm sample on the 400 square mile network. Similarly, average errors for beta deposition and storm rainfall volume were 39 percent and 23 percent, respectively. Thus, the sampling error was appreciably greater for beta concentration and deposition than for storm rainfall. This finding is in agreement with those found in the study of spatial relative variability, discussed earlier in this report.

TABLE 20

SINGLE POINT SAMPLING ERRORS ON EAST CENTRAL ILLINOIS NETWORK IN 1963

	Point Sampling Error, Percent		
Storm Date	Beta Concentration	Beta Deposition	Storm Rainfall
7/1	25	23	51
7/6		19	18
7/13	0	31	28
7/20	35	21	13
7/31	25	14	54
8/6	33	27	30
8/19	118	132	9
8/28	0	83	7
9/2	1	5	0
Average	30	39	23
Median	25	23	18

Comparison was made of the sampling errors on the 400 square mile network with those found on the Boneyard and Kaskaskia networks of 10 and 12 square miles in the 1962 study (Huff, 1963). Combining these two small networks, an average sampling error of 23 percent in beta concentration was found for a 15-storm sample. Average sampling errors of 22 percent and 9 percent, respectively, were found for beta deposition and storm rainfall on the small networks. Thus, as expected, the average sampling error was appreciably greater on the larger network, but it was certainly of significant proportions on both areas.

Huff and Neill (1957) have shown that the average sampling error in convective storms decreases with increasing areal mean rainfall. They found that when a centrally located raingage is used to determine the average depth of rainfall on an area of 400 square miles, the average and 95 percent sampling errors are as follows:

TABLE 21

AREAL REPRESENTATIVENESS OP POINT RAINFALL SAMPLES IN CONVECTIVE STORMS ON 400 SQUARE MILE AREA

Areal Mean (in.)	Average Sampling Error (%)	95 Percent Sampling Error (%)
0.25	40	100
o.5o	26	65
1.00	19	44
2.00	16	34

In Table 20, the average ratio of the error in beta concentration to that of storm rainfall is 1.3 and a ratio of 1.7 is indicated between beta deposition and storm rainfall. If these are representative ratios, then the average errors to be expected in the measurement of beta concentration and deposition by a single sample on an area of 400 square miles can be estimated by multiplying the values in Table 21 by the ratios. These estimates can only be considered a rough approximation at this time in view of the small number of storms upon which the ratios are based. However, data in Tables 20 and 21, along with results on the Boneyard and Kaskaskia networks presented in the first progress report, do stress the variability in radioactive rainout that is likely to occur within small areas In convective rainfall.

SUMMARY AND CONCLUSIONS

Beta Distribution Characteristics

Analyses were made of the characteristics of the gross beta distribution in convective storms through the use of time samples from 87 points in 29 storms. It was found that the distribution pattern of beta concentration through a storm could be grouped into four major and three minor types. The most frequent type (Type A) accounted for 45 percent of the cases, and Types A, B, C, and D together included approximately 90 percent of the cases. Type A is characterized by a relatively high concentration at the start of a storm followed by a rapid decrease to a minimum concentration when 60 to 80 percent of the rain has occurred, then an increase to a secondary maximum near the end of the storm period.

An investigation was made of the effect of various rainfall factors upon the shape of the distribution curves of beta concentration and upon the magnitude of the values along the curves. Factors investigated were total storm rainfall, rainfall duration, and average rainfall rate for the storm period. Results indicated that none of these rainfall factors exerted strong control over the characteristics of the beta concentration distribution.

Comparison of the types of beta distribution with synoptic weather types revealed no unique associations, although it was found that two of the major beta types (B+D) were biased strongly toward occurrences with warm fronts in 1963.

Rainfall rate was classified according to type of distribution in storms in the same manner as the gross beta concentration. Prom this classification, seven types were obtained, with the most frequent type accounting for 43 percent of the cases. Comparisons were then made between the gross beta and rainfall rate distributions, and these comparisons revealed several interesting relations. For example, the comparisons revealed a strong tendency for the minimum in the beta Type A curve to be associated with a major peak in the rainfall rate curve, but the beta minimum tends to lag the rate peak. On the average, the beta minimum was found to occur when 65 percent of the total storm rain had reached the ground, whereas the peak in the rainfall rate curve occurred when approximately 45 percent of the rain had fallen. Rainfall rate Type 1, a single-burst storm, occurred most frequently with beta Type A.

Analyses of the 1963 storms indicated that more than one type of beta distribution may occur at various stations in a relatively small area within a convective storm system, although a particular type of distribution usually dominates. Stage of storm development, depth of storm clouds, and, possibly, location of the sampling station with respect to a particular RW or TRW in a convective system are factors that may affect the distribution characteristics.

In general, it is concluded that a strong mathematical correlation will not be found consistently at a given point between beta concentration and rainfall rate because of the various types of beta distribution which prevail in convective storms, and because of the lag which occurs between peaks and valleys in the beta concentration and rainfall rate distribution patterns. However, a trend for an inverse relationship will be found, since the most frequent beta distribution (Type A), which accounted for approximately 45 percent of the occurrences in 1963, tends to minimize near the occurrence of a rainfall rate peak, and only one beta distribution, Type C, which accounted for 13 percent of the 1963 cases, frequently has a major peak near the major peak in the rainfall rate distribution. In Type C storms, a positive instead of an inverse correlation occurs.

Beta Concentration at Start and End of Storms

A strong trend was found for relatively high beta concentration at the start of 1963 storms and a lesser trend for an increase in concentration at the end of storms. In a study of 73 sets of time samples, a median of 1.8 was found for the ratio of the first to the second time sample in a storm. A median ratio of 1.2 was found between the last and next-to-last samples. The data were grouped by storm rainfall amount, duration, and average rate. This grouping revealed a trend for the ratio of initial beta concentration to the storm mean concentration to increase with increasing storm rainfall amount, but this trend was not found for the ratio of the last concentration to the mean concentration. No strong association was found between the ratios and synoptic weather type.

Analyses were performed to determine whether the trend for relatively high beta concentrations at the beginning of storm periods prevailed with individual bursts or showers occurring within a storm period comprised of two or more bursts. If not, it could be assumed to be a boundary condition, and determination of its cause would be simplified. Results of this analysis indicated a much weaker trend for high initial beta concentrations at the start of bursts within a storm system than at the forward edge of the storm system. A median ratio of 1.2 was found for the ratio of the first to the second time sample with the inner storm bursts, compared to 1.8 with the initial storm burst in the series. Thus, it appears that the high initial ratios are primarily, but not entirely, a border occurrence in convective systems. In turn, this indicates the high initial concentration may be closely related to evaporation from falling raindrops and/or contamination of the storm fringes by low-level or surface particulates.

An analysis was made of the distribution of particulates in the 1963 rainwater samples, in an effort to ascertain whether low-level and surface dirt are entrained into the edges of convective systems, particularly the forward edge. This analysis produced indirect evidence that the initially high beta concentration is partially due to contamination from low-level or surface particulates brought into a storm in the convergence process.

1962-1963 Strontium Analyses

Completion of the analyses of 1962 strontium data was accomplished. Results indicate that the areal relative variability of strontium concentration and deposition exeeed the storm rainfall variability, but the strontium variability is somewhat less than occurs with gross beta concentration and deposition.

In general, in point-to-point comparisons, relatively poor correlation was found between strontium deposition and concentration and three rainfall factors, total storm rainfall, rainfall duration, and average rainfall rate. The trend for low correlations, of course, would be expected in view of the findings in conjunction with the study of the distribution of beta concentrati on.

Prom a study of network patterns in 1962 storms, it was concluded that, with allowance for reasonable spatial displacement, the areal patterns of strontium deposition and storm rainfall are generally similar. The strontium concentration pattern is dictated more by developments in the convective cloud system, and does not show a consistent pattern relationship with storm rainfall, although there is a tendency for an inverse relationship between patterns.

Very limited analyses of 1963 strontium data have been made, since only 85 of the 400 samples shipped to Isotopes, Inc., for radiochemical analyses have been returned to date. A satisfactory relationship has been indicated between the strontium and gross beta rainout as a result of the limited analyses. If the observed trends continue to occur in future analyses, it appears that beta data can be used to provide an inexpensive source of data for radioactive rainout studies.

1963 Beta Analyses

Analyses of 1963 storms resulted in essentially the same conclusions with respect to point and areal correlations of gross beta concentration and deposition with rainfall volume, duration, and rate, as found with the more limited analyses of 1962 strontium data summarized earlier. Areal relative variability of gross beta concentration and deposition were found to increase with size of area sampled, and to be greater than the variability of storm rainfall on all areas studies in 1962-1963. Tests were made of the representativeness of a single point in calculating the average beta concentration and deposition on an area of 400 square miles; results indicated an average sampling error of 30 percent and 39 percent, respectively, for concentration and deposition, based on a 9-storm sample. The average sampling error for storm rainfall in the same group of storms was 23 percent.

RECOMMENDATIONS FOR FUTURE WORK

1. Efforts should be concentrated on further evaluation of the time distribution of radioactivity in 1964 through operation of the 16 time samplers within or near to the East Central Illinois network of 400 square miles. Experience gained in 1962-1963 indicates that an area of this size is optimum for mesoscale studies of radioactive rainout. This area is large enough to sample adequately convective cells, most thunderstorms, and significant portions of squall lines. Furthermore, the 50 raingages on the network provide a very detailed pattern of rainfall in time and space, and restriction of sampling to an area of this size facilitates radar surveillance of storms, and, consequently, leads to more detailed and more reliable radar observations for use in subsequent studies.

2. Efforts should be increased to accomplish mobile sampling within air mass storms, and to use the mobile equipment to augment network observations in special cases.

3. Further testing of the aircraft sampler should be made, and more attention devoted to collection of rainwater samples below cloud bases in widespread spring rains which are favorable for such sampling.

4. All radar sets should be utilized in efforts to track raindrops from the tropopause level to the surface sampling sites through radar reflectivity measurements, whenever possible. It is planned to use the TPS=10 for cloud top measurements, the CPS-9 for reflectivity measurements at various elevations in the atmosphere, and the M-33, 10-cm for surveillance in 1964 studies. The 10-cm unit of the M-33 was not in operation in 1962-1963.

5. Studies of the beta distribution patterns and their relationship to rainfall, rate should be continued to verify and to define further the relationships noted in 1963. Further investigation of the causes of the beta distribution characteristics should be pursued.

6. Mesoscale case studies of 1962 storms should be completed, along with analyses of the 1963 strontium data.

7. It is recommended that radiochemical analyses be limited to gross beta analyses in 1964. This will substantially reduce the costs of the research program, and expedite the analyses that have been delayed considerably in the past while awaiting results of strontium analyses. Results of analyses of 1962-1963 data performed to date indicate the utility of the gross beta data for radioactive rainout studies of the type being performed in Illinois, and the beta data will be even more useful in 1961; with the relatively long time that has elapsed since the last atmospheric nuclear tests.

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